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Pilot-Scale ESP (Electrostatic Precipitator) and Hydro-Sonic Scrubber Parametric Tests for Particulate, Metals and HCl Emissions

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The EPA's Office of Solid Waste is currently developing additional regulations to control emissions of particulate matter, toxic metals and hydrochloric acid (HCl) from hazardous waste incinerators. Emissions data was collected to support these regulations; testing was conducted on two pilot-scale air pollution control systems installed and operated in Tulsa, OK. The test program took place between March 28 and April 4, 1989. This report represents the results of the testing program and describes the processes involved as well as the testing and analytical methods used. The primary objective of the test program was to collect particualte and toxic metals removal efficiency and emissions data for two pilot-scale air pollution control systems--hydro-sonic wet scrubber; and beltran two-stage electrostatic precipitator.

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DRAFT TEST REPORT

PILOT-SCALE ESP AND HYDRO-SONIC SCRUBBER PARAMETRIC TESTS FOR PARTICULATE, METALS AND HCl EMISSIONS

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SECTION 1

INTRODUCTION

The Environmental Protection Agency's Office of Solid Waste (EPA/OSW) is currently developing additional regulations to control emissions of particulate matter, toxic metals and hydrochloric acid (HCl) from hazardous waste incinerators. Radian Corporation, under subcontract to Versar, Inc., was contracted by the EPA to collect emissions data to support these regulations. The testing was conducted on two pilot-scale air pollution control systems installed and operated at the John Zink Company Research Facility in Tulsa, Oklahoma. The test program took place between March 28 and April 4, 1989. This report presents the results of the testing program and describes the processes involved as well as the testing and analytical methods used.

The primary objective of the test program was to collect particulate and toxic metals removal efficiency and emissions data for two pilot-scale air pollution control systems:

- A Hydro-Sonic® wet scrubber; and
- A Beltran two-stage electrostatic precipitator (ESP).

The toxic metals examined in this test program were arsenic (As), cadmium (Cd), chromium (Cr), lead (Pb) and mercury (Hg). The control devices were tested using a flue gas stream generated by injecting an ash containing the toxic metals into a natural gas fired horizontal incinerator. An

organo-arsenic compound (monosodium methylarsonic acid) and a salt ($Al_2(SO_4)_3$) solution were also injected into the incinerator to generate submicron metal fume and inert submicron particulates, respectively. Carbon tetrachloride was fired to produce HCl and thus simulate the flue gas conditions of a hazardous waste incinerator firing chlorinated waste.

A second objective of the test program was to evaluate the potential use of a surrogate metal mixture as a means of assessing control efficiencies, establishing allowable waste feed metals concentrations and stack emission levels for the toxic metals.[1] To accomplish this objective, four selected metals, copper (Cu), bismuth (Bi), strontium (Sr), and magnesium (Mg), were also fed into the incinerator during the testing. In combination, these surrogate metals are expected to represent all of the toxic metals with respect to volatility and behavior in the combustion system, e.g. likelihood of fume formation or entrainment. The surrogate metals mixture was fed to the incinerator to provide a draft comparison of removal efficiencies and emission levels for the surrogate and toxic metals.

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[1] R.G. Burton, W.D. Clark and W.R. Seeker, EER, Draft Topical Report - Surrogate Metals Mixture, EPA Contract 68-03-3365, Engineering Analysis of Hazardous Waste Thermal Destruction, October 1988.

SECTION 2

PROCESS DESCRIPTION AND OPERATION

2.1 PROCESS DESCRIPTION

The pilot-scale test system consisted of a natural gas-fired incinerator followed by the emission control equipment. The horizontal fired incinerator has a design heat value of 4.5 million BTU/hour, with a gas residence time of approximately two seconds. The incinerator was fired at temperatures near 1600°F and the MSW fly ash and other materials were injected into the incinerator as appropriate to achieve desired particulate loadings and particle size distributions. Details of the test conditions are discussed in Section 2.2.

The flue gas was directed from the incinerator to a conditioning tower where the temperature was lowered to approximately 550°F by direct contact with water. Gas flow rates at this point ranged from 650 to 950 dscfm. From the conditioning tower, the flue gas was passed through a quench pot where temperatures were lowered to approximately 180°F. The flow was then directed to the air pollution control system to be tested.

For tests on the two-stage ESP system, a slip stream of approximately 130 dscfm (218 acfm at 145°F) was diverted to the ESP inlet, as shown in Figure 2-1. A conventional variable throat venturi was in-line upstream of the ESP, but was operated with the throat fully open (two inches of water pressure drop) and used only for scrubbing HCl from the gas stream. During the Hydro-Sonic scrubber performance tests, the venturi scrubber was bypassed and the entire flow of flue gas was directed to the scrubber (Figure 2-3). Flue gas was pulled through the control system by an induced draft fan, and

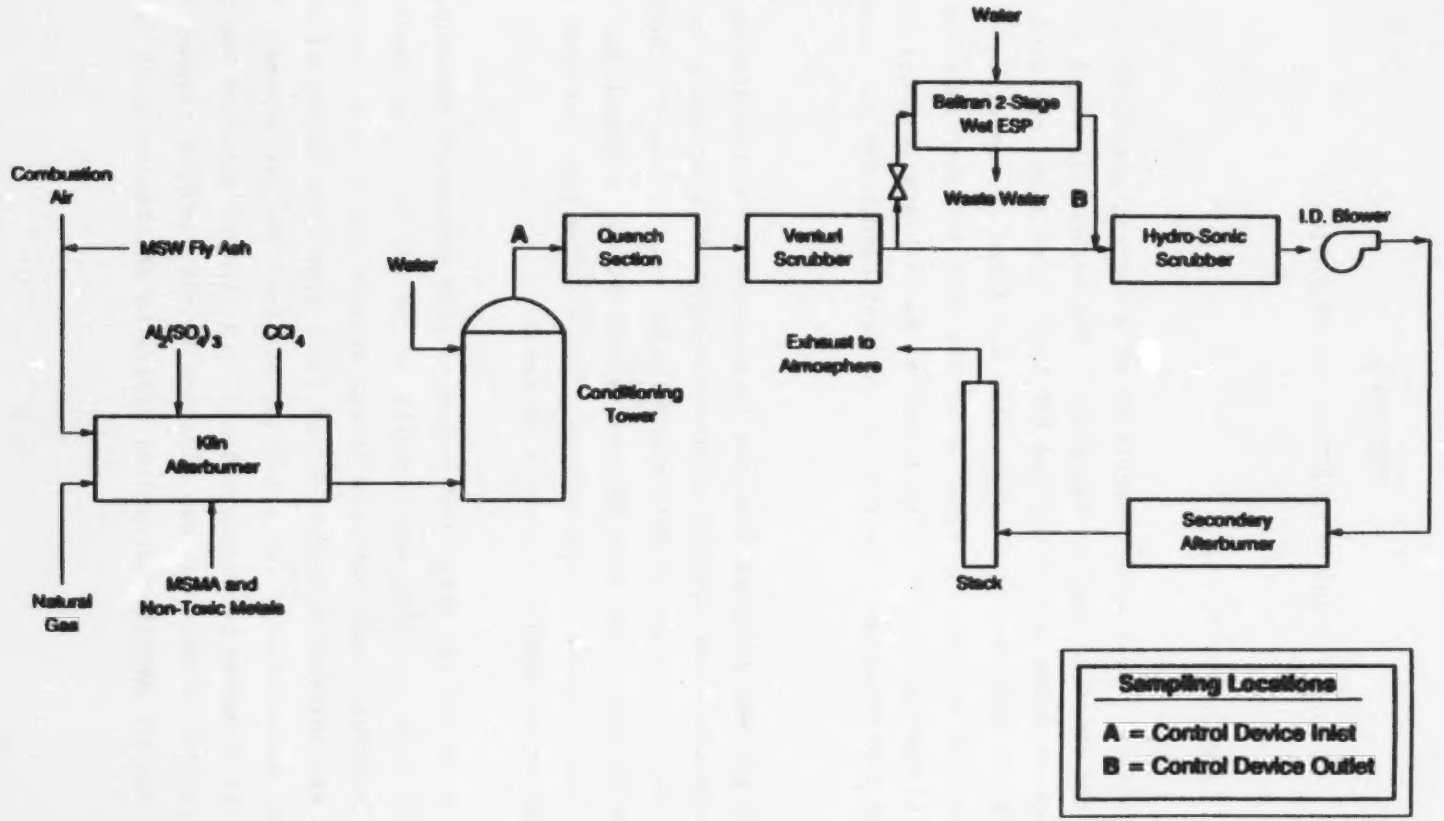

Figure 2-1. Process Flow Diagram with Sampling Locations for the Wet-ESP Trials at the John Zinc Company Research Facility

then directed through a secondary afterburner and to the atmosphere via a stack. Each of the air pollution control systems is described in detail in the sections below.

2.1.1 Beltran Two-Stage ESP

The pilot-scale Beltran two-stage ESP was a tubular precipitator designed for particulate and acid gas emission control. A schematic diagram of the Beltran two-stage ESP is shown in Figure 2-2. Flue gas entering the ESP first passes through a small pre-cleaning section intended to saturate the gas with moisture and remove large particles. The flue gas then passes into the first stage of the ESP where particulate is charged and subsequently collected. During this test program, the ESP was operated dry, with no water sprayed to the pre-cleaning section. The Beltran operator claimed that sufficient moisture was present in the gas stream.

2.1.2 Hydro-Sonic Scrubber

Upon completion of the ESP trials, the venturi scrubber was removed and the entire gas flow was directed to the Hydro-Sonic scrubber as shown in Figure 2-3. The pilot-scale Hydro-Sonic scrubber tested was a Supersub Fan/Ejector Drive Tandem Nozzle System. A schematic for the Hydro-Sonic system is shown in Figure 2-4. The flue gas exiting the quench pot passes through a venturi section where the gas stream is saturated at approximately 175°F. Flue gases then pass into the first of the tandem nozzle systems. The flue gas, water and steam first pass through a supersonic ejector nozzle contained within a subsonic ejector nozzle. The area surrounding the subsonic nozzle is operated under negative pressure, creating a cone shaped standing wave consisting of high localized pressure gradients at the nozzle exit. In addition, water is injected through vee-jet spray tips around the nozzle exit (countercurrent to the gas flow). Water encountering the gas exiting the nozzle is atomized forming small irregularly shaped droplets which serve as impact targets onto which particulate, metal salt and metal oxides collide and

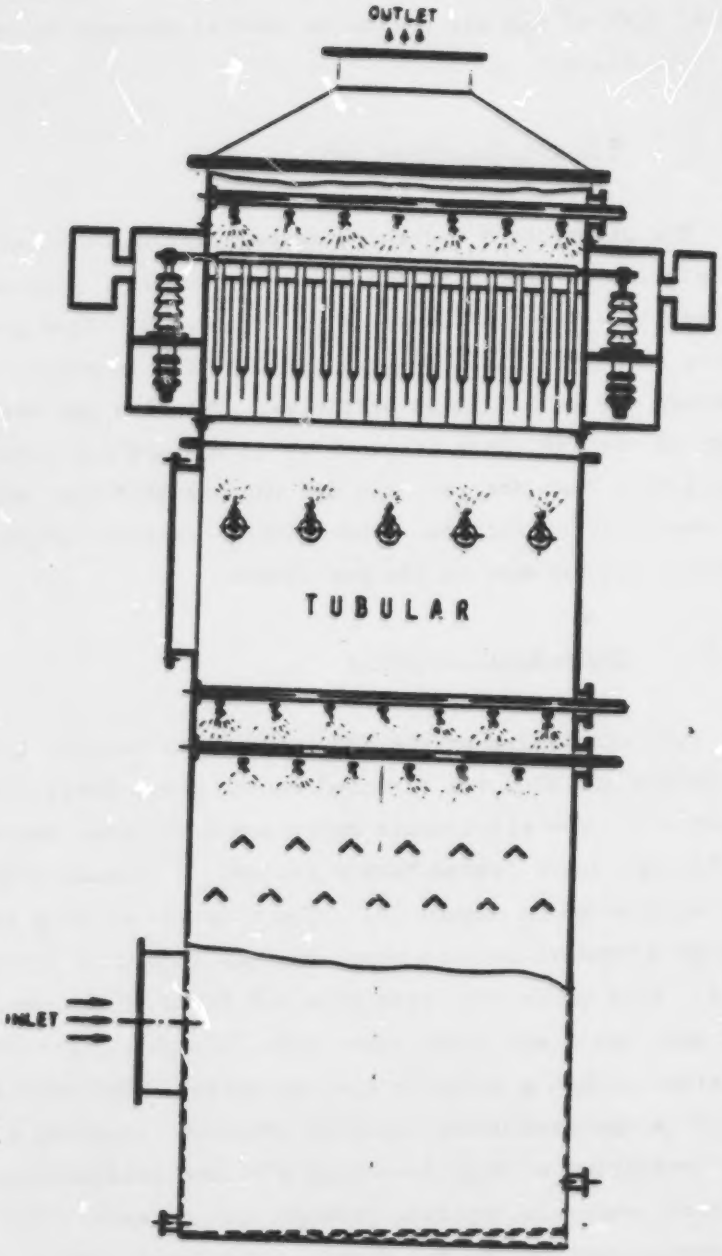

Figure 2-2. Schematic Diagram of the Beltran Two-Stage Wet Electrostatic Precipitator

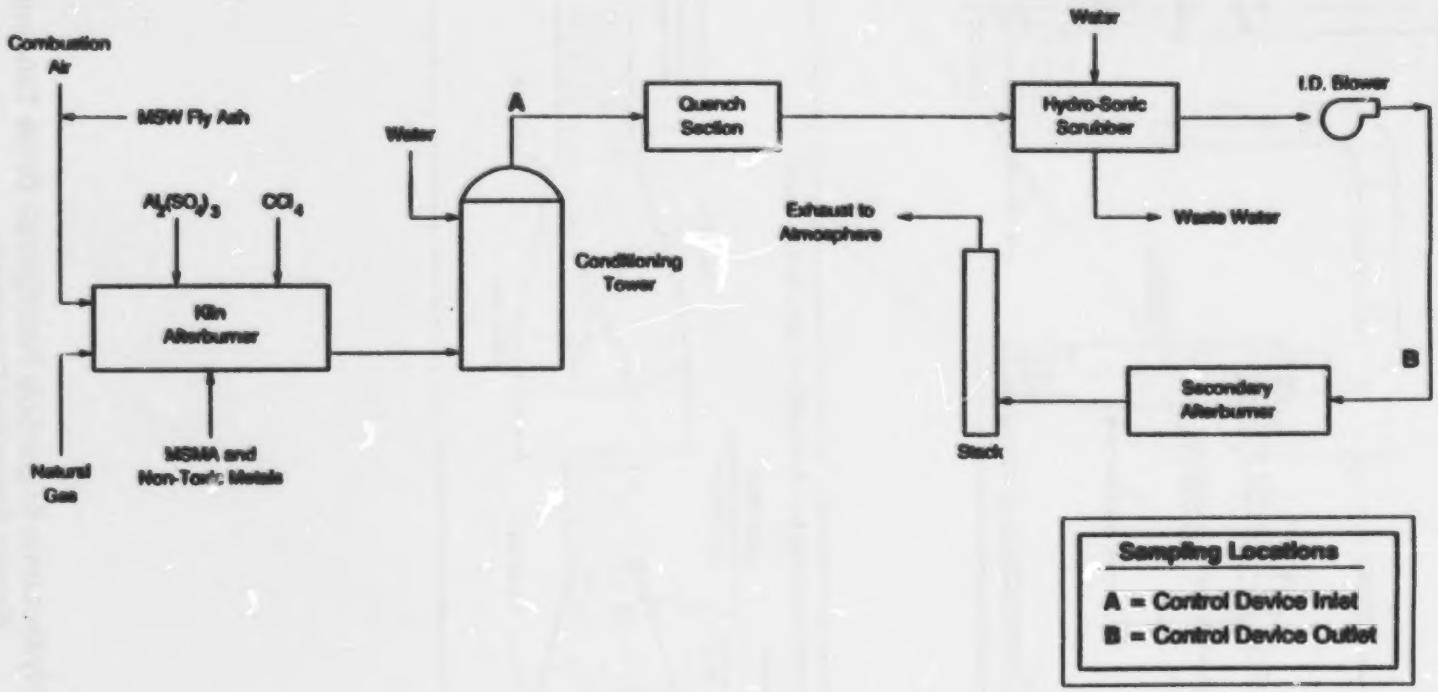

Figure 2-3. Process Flow Diagram with Sampling Locations for the Hydro-Sonic Scrubber Trials at the John Zinc Company Research Facility

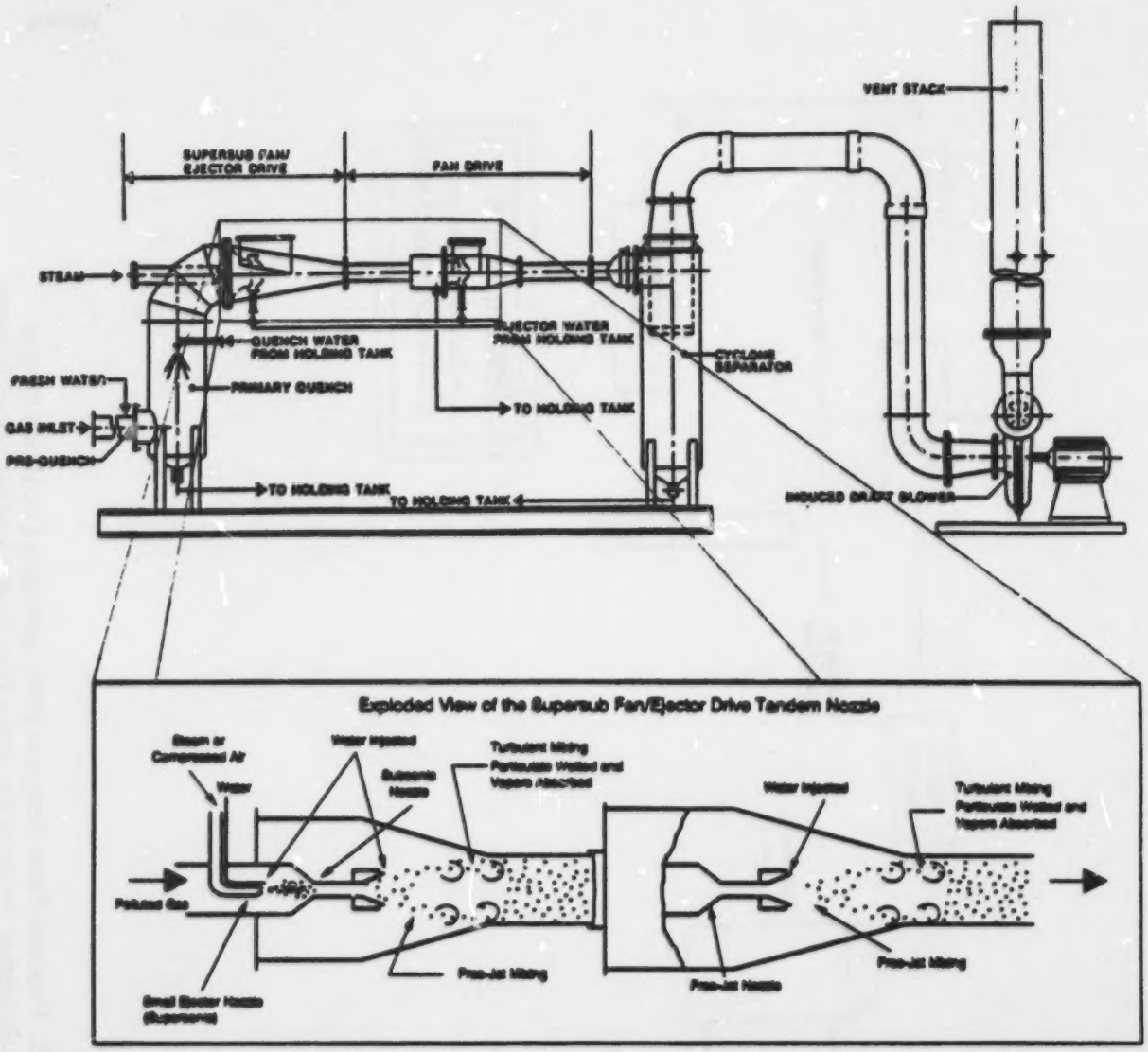

Figure 2-4. Hydrosonic SuperSub Fan/Ejector Drive Tandem Nozzle Scrubber Schematic

are captured. The cone shaped area where the atomization and impaction occurs is called the mixing zone. The mixture then passes into a mixing tube section where agglomeration of water droplets occurs.

The flue gas containing these water droplets passes through stage of supersonic - subsonic nozzles, a mixing zone and a mixing tube identical to the first stage except that steam is not used in the supersonic nozzle. The flue gas then passes through a cyclonic separator where the agglomerated water droplets are collected and removed.

2.2 PROCESS OPERATION

The purpose of this test program was to evaluate the performance of two air pollution control systems for use in particulate and toxic metals emission control for hazardous waste incinerators. The test program was designed to evaluate the air pollution control system performance at two levels of total particulate loading and with two particle size distributions. In order to have better control of the flue gas composition, a horizontal natural gas-fired incinerator was used to develop a simulated hazardous waste flue gas. The desired particulate loading, particle size distribution (PSD), and metals content of the flue gas was controlled by injecting appropriate quantities of the following materials:

- MSW ash* and bismuth nitrate were co-fired into the incinerator with natural gas. A predetermined quantity of the mix was continuously fed into a screw auger feed mechanism which conveyed the material into the incinerator burner;

---

*The ash was collected as a composite sample from a multiple field ESP on a mass burn municipal waste incinerator. The ash contains material collected in all fields of the ESP.

- An aqueous solution containing monosodium methylarsonic acid (MSMA), strontium nitrate, cupric nitrate, and magnesium nitrate was injected through a lance into the flame at the exit of the burner;

- A 30 percent aqueous solution of aluminum sulfate was injected through a lance and into the flame at the exit of the burner, and

- A carbon tetrachloride solution was injected through a lance into the flame at the exit of the burner (to produce HCl).

During this program, tests were conducted at four flue gas grain loading conditions:

1. 2 gr/dscf and a low percentage of sub-micron particulate (hereafter referred to as low/low);
2. 2 gr/dscf and a high percentage of sub-micron particulate (hereafter referred to as low/high);
3. 10 gr/dscf and a low percentage of sub-micron particulate (hereafter referred to as high/low); and
4. 10 gr/dscf and a high percentage of sub-micron particulate (hereafter referred to as high/high).

Particulate loadings of 2 gr/dscf and 10 gr/dscf were selected for testing to represent the lower loadings expected from liquid-fired incinerators and the higher loadings expected from rotary kilns treating containerized wastes and contaminated soils and debris. Effective removal of sub-micron particulate have been purported to be essential in achieving lower overall total particulate concentrations (i.e., less than 0.08 grains/dscf). The fraction of sub-micron particulate present in the gas stream was varied by changing the ratio of MSW ash to aluminum sulfate injected into the gas stream to obtain the desired particulate loading. Feed rates for each of the materials injected into the afterburner during the four different test conditions are summarized in Table 2-1.

TABLE 2-1. TEST MATERIAL FEED RATES

Test Condition									
Particulate Loading (gr/dscf)	Particle Size Distribution[a]	NSW (Lb/hr)	$Al_2(SO_4)_3$ (Lb/hr)	NSMA (g/hr)	CCL_4 (Lb/hr)	$Cu(NO_3)_2.3H_2O$ (g/hr)	$Bi(NO_3)_3.5H_2O$ (g/hr)	$Sr(NO_3)_2$ (g/hr)	$Mg(NO_3)_2.6H_2O$ (g/hr)
2	Low	11	6	65	10	100	100	100	450
2	High	6	11	65	10	100	100	100	450
10	Low	55	25	65	10	100	100	100	450
10	High	25	55	65	10	100	100	100	450

[a] "Low" designates a low percentage of submicron size particulate.
"High" designates a high percentage of submicron size particulate.

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Injection of the MSW fly ash provided large particles, as well as some of the desired toxic metals. A mass distribution determined for the MSW fly ash by scanning electron microscope (SEM) is shown in Table 2-2. It can be seen that approximately 53 percent (by weight) of the ash is smaller than 40 to 80 microns. The concentration of As, Cd, Cr, Pb, and Hg present in the MSW fly ash is shown in Table 2-3.

The concentration of sub-micron particulate and acid gases was controlled by adjusting the feed rates of aluminum sulfate, MSMA, and carbon tetrachloride. The aluminum sulfate ($Al_2(SO_4)_3$) provided moderate to sub-micron size particulate as Al_2O_3 and acid gases as SO_2/SO_3. The MSMA ($NaCH_4AsO_3$) was chosen to provide a sub-micron fume as As_2O_3 and sub-micron particulate as NaCl. The carbon tetrachloride provided HCl.

The initial test plan specified that the surrogate metals (bismuth, copper, magnesium and strontium) be injected into the incinerator as an aqueous solution. However, after conducting small scale mixing tests in the field, it was determined that the bismuth nitrate did not dissolve completely into solution with the other non-toxic metals. This was apparently due to the poor water solubility of bismuth nitrate. The bismuth nitrate was, therefore, blended with the MSW ash and fed through a screw auger into the incinerator burner.

A summary of the feed conditions tested for the two-stage ESP and for the Hydro-Sonic scrubber is presented in Table 2-4. Original plans called for conducting a total of four test conditions with the ESP. However, insufficient time and resources were available to complete all four tests, due to difficulties in obtaining desired gas flow rates through the ESP and delays in installing a functional drain system for the pilot unit. Three tests were completed; however, the first test run was invalidated due to a number of process and sampling problems. These problems included a high gas flow through the ESP, water in the duct leading to the ESP, and in the ESP, improper input rates for the feed materials and discoloring of the outlet particulate filter by water from the ESP.

TABLE 2-2. SUMMARY OF SEM RESULTS FOR RADIAN -200 MESH FLY ASH SAMPLE

Particle Size Range (um)	Mass Distribution (Wt. %)
0.2 - 1.0	< 1
1.0 - 2.5	< 1
2.5 - 5.0	2
5.0 - 10	4
10 - 20	16
20 - 40	29
40 - 80	47

TABLE 2-3. METALS CONCENTRATIONS IN MSW ESP ASH

Metal	Pre-Test Sample	4/1/89 Sample	4/3/89 Sample
Cadmium	466	500	440
Chromium	129	174	114
Lead	5640	4960	4770
Arsenic	374	160	221
Mercury	48	39.8	54.8
Bismuth	--	<160	<160
Copper	--	720	760
Magnesium	--	8600	8200
Strontium	--	280	300

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TABLE 2-4. SUMMARY OF EXPERIMENTAL TEST CONDITIONS

Air Pollution Control System	Test Run	Particulate[a] Loading	Particle Size[b] Distribution
Two-Stage ESP	1[c]	Low	Low
	2	Low	High
	3	High	High
Hydro-Sonic® Scrubber	4[d]	Low	Low
	5	Low	High
	6	High	Low
	7	High	High
	8[d]	Low	Low
	9[d]	Low	Low

[a]Low particulate loading = 2 gr/dscf; high particulate loading = 10 gr/dscf

[b]Low and high particle size conditions represent low and high fractions of submicron particles.

[c]This test run was invalidated due to a number of process and sampling problems.

[d]Replicate tests to determine combined process, sampling, and analytical precision.

A total of ten test runs were performed with the Hydro-Sonic® scrubber. Six of these tests were a part of the original EPA test program. These tests included one test run at each of the four test conditions, plus two additional replicate tests at the low grain loading/low fraction of sub-micron particles. The replicate tests were performed to provide a measure of the combined process, sampling and analytical precision. The final four test runs which were conducted at the low/low test condition were performed for the John Zink Company and are reported in this EPA report as supplemental data. These tests were performed to assess the effect of scrubber pressure drop and steam use on particulate removal effectiveness.

SECTION 3

SUMMARY OF RESULTS

Final results for particulate matter, metals and HCl emissions and particle size distribution testing conducted at the John Zink facility on a pilot-scale 2-stage ESP and a Hydro-Sonic scrubber are presented in this section. Total particulate results are presented in Section 3.1, metals results are presented in Section 3.2, particle size data are discussed in Section 3.3 and the HCl results are presented in Section 3.4.

3.1 PARTICULATE MATTER RESULTS

Sampling for flue gas particulate matter/metals emissions was conducted simultaneously at the control device inlet and outlet according to a draft EPA/EMSL method entitled "Methodology for the Determination of Trace Metal Emissions in Exhaust Gases from Stationary Source Combustion Processes." Particulate matter emissions were measured during two valid test runs conducted on the 2-stage ESP (Runs 2 and 3) and during 10 test runs conducted on the Hydro-Sonic scrubber (Runs 4 through 13). Test Run 1 on the ESP was invalidated due to both process and sampling problems. Inlet and outlet particulate sampling results are discussed separately in the sections below.

3.1.1 Control Device Inlet Results

Particulate concentrations and mass emission rates for sampling conducted at the quench tower inlet (inlet) are summarized in Table 3-1. The inlet results show particulate loadings ranging from 0.87 to 1.70 gr/dscf for the "low loading" test condition and particulate loadings ranging from 3.06 to 4.60 for the high loading tests. The measured

TABLE 3-1. SUMMARY OF INLET PARTICULATE EMISSION CONCENTRATIONS AND MASS EMISSION RATES

TEST RUN NUMBER	2	3	4	5	6	7	8	9	10	11	12
CONTROL SYSTEM	ESP		Hydro-Sonic Scrubber								
LOADING CONDITION	LOW	HIGH	LOW	LOW	HIGH	HIGH	LOW	LOW	LOW	LOW	LOW
PSD CONDITION	HIGH	HIGH	LOW	HIGH	LOW	HIGH	LOW	LOW	LOW	LOW	LOW
STACK TEMP. (F)	500	520	473	449	476	507	497	488	515	523	523
OXYGEN (%V)	7.3[a]	6.1	8.7	8.2	6.4[a]	6.5	5.2	4.1	5.3	5.8	5.1
GRAIN LOADING (GR/DSCF)	0.907	3.059	1.158	0.872	3.405	4.604	1.703	1.217	1.280	1.249	1.326
MASS RATE (LBS/HR)	5.11	20.04	9.12	7.12	21.60	29.43	10.91	7.28	9.11	8.79	9.10

[a]Value recorded from plant process data. Emission testing value considered suspect.

particulate loadings represent approximately 30 to 70 percent of the loadings targeted. The difference between the amount of material injected and the mass loadings found in the gas stream is believed to be due to loss or drop out of material in the incinerator or ducting prior to the inlet sampling point. Some ash was found in the incinerator upon completion of the testing. Comparison of the mass rate of metals fed to the incinerator compared to the mass rate of metals determined at the inlet sampling point shows similar results and is discussed further in Section 3.2.

3.1.2 ESP Outlet Results

Particulate sampling results for the ESP outlet are summarized along with ESP particulate removal efficiencies in Table 3-2. Oxygen data presented in Table 3-2 for the ESP tests show that a significant amount of air in-leakage occurred between the quench tower inlet and ESP outlet sampling points. The oxygen concentration at the inlet was 7.3 and 6.1 percent for the two tests, and the corresponding ESP outlet oxygen concentrations were 17.8 and 18.0 percent. Static pressure through the ESP was approximately -35 inches of water and the air in-leakage is believed to have occurred through a flange at which a restriction plate was installed just prior to Runs 2 and 3 (see Figure 4-4) and through two half-inch holes opened in ports on the side of the ESP by the Beltran operator. The ports were installed to provide purge air for the electronic insulators and the restriction plate was installed to reduce flow through the ESP to the desired 200 acfm.

ESP outlet particulate concentrations were 0.0072 gr/dscf at 7 percent O_2 for the low particulate loading/high fraction of fine particles (low/high) condition and 0.0279 gr/dscf at 7 percent O_2 for the high particulate loading/high fraction of fine particles (high/high) condition. The higher outlet concentration for the high/high condition was apparently caused by the higher particulate loading entering the ESP.

TABLE 3-2. SUMMARY OF ESP OUTLET TEST RESULTS

Run Number	Test Condition[a]	Particulate Concentration			Mass Emission Rate		Particulate Removal Efficiency (%)[b]	Flue Gas Oxygen Concentration	
		Inlet (gr/dscf)	Outlet (gr/dscf)	Outlet (gr/dscf @ 7%)	Inlet (lbs/hr)	Outlet (lbs/hr)		Inlet (% V)	Outlet (% V)
2	Low/High	0.907	0.0016	0.0072	5.11	0.00165	99.2	7.3[c]	17.8
3	High/High	3.059	0.0058	0.0279	20.0	0.00705	99.8	6.1	18.0

[a] Test Condition refers to grain loading condition/proportion of submicron particles.
[b] Calculated based on grain loading values corrected to 7% O_2.
[c] Value recorded from plant process data. Emission testing value was considered suspect.

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3.1.3 Hydro-Sonic Scrubber Outlet Results

Tests conducted on the Hydro-Sonic scrubber were performed at different scrubber pressure drops, with and without steam injection, and at different particulate loadings and particle size distributions.

Results for test Runs 4 through 9 are presented in Table 3-3. These test runs were all conducted with an overall scrubber pressure drop of approximately 51 inches of water and with steam injection. Runs 4, 8 and 9 represent replicate tests performed at the low/low test condition. These test runs provide a measure of the combined process, sampling and analytical precision for the test program. Outlet particulate concentrations measured for Runs 4, 8 and 9 ranged from 0.0025 to 0.0056 gr/dscf at 7 percent O_2, with a standard deviation of 0.0017 gr/dscf.

The replicate test runs (4, 8 and 9) and Runs 5, 6 and 7 were conducted at the four different particulate loadings and particle size distributions discussed in Section 3.2. Statistical comparison of outlet particulate concentrations determined for the replicate tests with outlet concentrations determined for Runs 5, 6 and 7 shows that the results for all six test runs are statistically the same. This means that variations in particulate loading and the fraction of fine particulates did not have a statistically significant effect on the performance of the Hydro-Sonic scrubber in terms of the achievable outlet particulate emission concentration. The average outlet particulate concentration for the six test runs (Runs 4 through 9) is 0.0047 gr/dscf at 7 percent O_2.

Particulate concentrations for test Runs 10, 11, 12 and 13 are presented in Table 3-4, along with the average concentration for Runs 4, 8 and 9. Test Runs 10, 11, and 12 were conducted at a lower pressure drop, approximately 36 inches of water, without steam injection. Test Run 13 was also conducted at a pressure drop of 36 inches of water, but with steam injection. All of the data presented in Table 3-4 is for tests conducted at the low/low test condition.

TABLE 3-3. SUMMARY OF HYDRO-SONIC OUTLET TEST RESULTS

Run Number	Test Condition[a]	Particulate Concentration			Mass Emission Rate		Particulate Removal Efficiency (%)	Flue Gas Oxygen Concentration	
		Inlet (gr/dscf)	Outlet (gr/dscf)	Outlet (gr/dscf @ 7% O_2)	Inlet (lbs/hr)	Outlet (lbs/hr)		Inlet (% V)	Outlet (% V)
4	Low/Low	1.16	0.0040	0.0045	9.12	0.0325	99.6	8.7	8.5[b]
5	Low/High	0.872	0.0032	0.0037	7.12	0.0264	99.6	8.2	8.8
6	High/Low	3.41	0.0043	0.0042	21.6	0.0285	99.9	6.4[b]	6.7
7	High/High	4.60	0.0067	0.0068	29.4	0.0494	99.8	6.5	7.2
8	Low/Low	1.70	0.0056	0.0056	10.9	0.0400	99.6	5.2	7.1
9	Low/Low	1.22	0.0027	0.0025	7.28	0.0192	99.7	4.1	5.9

[a] Test Condition refers to grain loading condition.

[b] Value recorded from plant process data. Emission testing value was considered suspect.

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TABLE 3-4. SUMMARY OF HYDRO-SONIC OUTLET TEST RESULTS COMPARING SCRUBBER STEAM AND PRESSURE DROP PARAMETERS

Run Number	Scrubber Conditions		Particulate Concentration			Mass Emission Rate		Particulate Removal Efficiency (%)	Flue Gas Oxygen Concentration	
	Scrubber Steam Usage	Scrubber Delta P (H_2O)	Inlet (gr/dscf)	Outlet (gr/dsf)	Outlet (gr/dscf @ 7% O_2)	Inlet (lbs/hr)	Outlet (lbs/hr)		Inlet (% V)	Outlet (% V)
4, 8 and 9 Average	Yes	51.6	1.36	0.0041	0.0042	9.10	0.0306	99.6	6.0	7.2
10	No	35.8	1.28	0.0120	0.012	9.11	0.0992	98.9	5.3	7.0
11	No	35.8	1.25	0.0129	0.0125	8.79	0.103	98.8	5.8	6.5
12	No	35.9	1.33	0.0124	0.0125	9.10	0.0977	98.9	5.1	7.1
10 - 12 Average	No	35.8	1.29	0.0124	0.012	9.00	0.100	98.9	5.4	6.7
13	Yes	36.2	NS[a]	.0097	.0091	NS	0.0739	NA[b]	NS	6.9

[a] NS = Not Sampled.

[b] NA = Not Applicable.

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The average outlet particulate concentration for Runs 10, 11, and 12 was 0.0123 gr/dscf at 7 percent O_2. Comparison of the average particulate concentrations for Runs 10, 11 and 12 with average concentration for Runs 4, 8 and 9 shows a statistically significant increase in outlet particulate concentration for the lower pressure drop, without steam test.

The outlet particulate concentration measured for Run 13 was 0.0091 gr/dscf at 7 percent O_2. Comparison of this concentration with the average concentration for Runs 10, 11 and 12 shows a slight, but statistically significant, reduction in the outlet particulate emissions with the addition of steam. Thus, data presented in Table 3-4 show the expected result of reduced particulate emissions with 1) higher scrubber pressure drop and 2) steam injection.

3.1.4 Gas Sampling Parameters and Conditions

Gas sampling parameters and conditions, including test dates, sampling times, flue gas parameters and isokinetic calculation results are presented in Table 3-5. Comparison of inlet and outlet gas flow rates for the ESP on a dry standard basis (dscfm) shows the lower slip stream flow through the ESP. Inlet and outlet flow rates for the Hydro-Sonics show acceptable agreement, when changes in oxygen content due to air in-leakage are considered.

Results for isokinetic sampling rate calculations are within the QC objective of 100 ± 10 percent for all of the inlet test runs and for the ESP outlet tests. Hydro-Sonic outlet isokinetic sampling rates are reported as a range due to uncertainty in the actual moisture content of flue gas at this sample point. These isokinetic results are discussed in detail with other QA/QC results in Section 6.0.

TABLE 3-5. SUMMARY OF GAS SAMPLING PARAMETERS AND CONDITIONS FOR PARTICULATE/METALS SAMPLING

TEST DATE	3/30/89	3/30/89	4/01/89	4/01/89	4/03/89	4/03/89	4/04/89	4/04/89	4/5/89	4/5/89	4/5/89	4/5/89
TEST RUN NUMBER	2	3	4	5	6	7	8	9	10	11	12	13
LOADING CONDITION	LOW	LOW	HIGH	LOW	HIGH	HIGH	LOW	LOW	LOW	LOW	LOW	LOW
PSD CONDITION	LOW	HIGH	HIGH	HIGH	LOW	HIGH	LOW	LOW	LOW	LOW	LOW	LOW
INLET												
TIME	11:02-11:32	15:52-17:07	11:32-13:55	15:39-17:49	10:03-13:03	14:56-17:05	11:58-14:05	16:41-19:24	11:12-12:20	13:49-15:02	16:12-17:24	Not Sampled
STACK TEMP. (F)	500[b]	520	473	449	476[b]	507	497	488	515	523	523	
OXYGEN (%V)	7.3	6.1	8.7	8.2	6.4	6.5	5.2	4.1	5.3	5.8	5.1	
STACK MOISTURE (%V)	59.4	55.4	51.3	51.8	53.8	57.2	56.3	58.6	57.0	57.3	58.4	
VOL. FLOW RATE (ACFM)	3088	3332	3467	3555	2996	3366	3221	3144	3551	3556	3565	
VOL. FLOW RATE (DSCFM)	658	764	918	953	740	746	747	697	830	821	801	
PERCENT ISOKINETIC	112.5	101.8	87.4	87.9	95.1	101.3	101.4	108.0	103.2	103.6	105.5	
OUTLET												
TIME	10:58-13:19	15:51-18:27	11:35-14:21	15:42-18:21	10:10-13:39	14:50-17:33	11:56-14:39	16:41-19:46	11:12-12:46	13:49-14:59	16:12-17:20	18:06-19:11
STACK TEMP. (F)	150	139	226[b]	223	230	230	225	228	224	233	233	237
OXYGEN (%V)	17.8	18.0	8.5	8.8	6.7	7.2	7.1	5.9	7.0	6.5	7.1	6.2
STACK MOISTURE (%V)	28.9	22.7	53.2	53.8	55.4	54.5	57.4	58.7	56.6	57.1	58.3	59.2
VOL. FLOW RATE (ACFM)	210	226	2630	2746	2338	2514	2551	2666	2881	2842	2891	2870
VOL. FLOW RATE (DSCFM)	120	142	942	971	783	858	834	841	966	931	921	890
PERCENT ISOKINETIC[a]	95.8	98.3	99-114	104-118	108-124	102-116	101-120	96-116	108-120	107-120	112-124	112-126

[a] See discussion in Qa/QC section for explanation of isokinetic ranges.

[b] Value recorded from plant process data. Emission testing value was considered suspect.

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3.2 METALS RESULTS

Flue gas particulate/metals samples from Runs 2 through 9 were analyzed at Radian's Laboratories for the following metals: arsenic, bismuth, cadmium, chromium, copper, lead, magnesium, mercury, and strontium. Test results for inlet samples, outlet samples, removal efficiencies and metals-to-particulate ratios are discussed separately in the sections below.

3.2.1 Inlet to the Control Device

The mass rate of the metals measured at the control device inlet is presented in Table 3-6. The mass rates were determined from the metals concentration in the flue gas and the flue gas volumetric flow rate. As expected, the metals mass rates vary with the mix and input rate of the various feed materials.

Metals feed rates calculated from feed material inputs are compared with measured metals mass rates in Table 3-7. Comparison of these data in terms of percent recovery of the mass spiked indicates the following:

- Recovery of Cd, Cr, Pb, and Hg, which were present only in the MSW ash appears to be relatively high, ranging from 73 to 100+ percent for three of the four test conditions.

- Recovery of Bi, Cu, and As from the metals spikes was moderate, ranging from 23 to 53 percent.

- Recovery of strontium (from the surrogate metals spike) and magnesium (from both the MSW ash and the surrogate metals spike) was poor, ranging from about 6 to 17 percent for strontium and 1 to 6 percent for magnesium.

TABLE 3-6. SUMMARY OF THE INLET METALS MASS RATES FOR THE JOHN ZINK TEST PROGRAM.

TEST CONDITION	Low/High	High/High	Low/Low	Low/High	High/Low	High/High	Low/Low	Low/Low
	MASS RATE (grams/hour)[a]							
Parameter	RUN 2	RUN 3	RUN 4	RUN 5	RUN 6	RUN 7	RUN 8	RUN 9
Arsenic	14.3	13.2	21.4	12.5	17.7	20.8	7.97	16.7
Bismith	7.66	1.94	24.8	12.5	22.0	24.2	7.59	13.5
Cadmium	1.32	3.88	1.92	1.36	4.56	4.62	1.44	1.83
Chromium	0.281	1.18	0.802	0.600	1.13	1.82	0.492	0.796
Copper	10.6	10.1	22.6	5.67	17.3	11.3	5.96	4.92
Lead	16.0	46.4	23.0	13.0	49.2	53.0	13.9	23.1
Magnesium	4.39	[4.28]	7.00	1.13	3.14	5.13	3.08	5.68
Mercury	0.134	0.469	0.210	0.156	0.548	0.458	0.200	0.188
Strontium	7.10	1.71	7.68	3.62	4.23	4.11	3.28	10.6

[a] Brackets indicate that the metal was not detected. Values in brackets are minimum detection limits.

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TABLE 3-7 A COMPARISON OF METALS FEEDS VERSUS ACTUAL MASS RATES MEASURED AT THE INLET

Condition	MSW Ash Conc. (ug/g)	Metals Salts Feed Rate[a] (g/hr)	low/low			low/high			high/low			high/high		
			Total Feed Rate[b] (g/hr)	Inlet Mass Rate (g/hr)	Percent Recovery	Total Feed Rate (g/hr)	Inlet Mass Rate (g/hr)	Percent Recovery	Total Feed Rate (g/hr)	Inlet Mass Rate (g/hr)	Percent Recovery	Total Feed Rate (g/hr)	Inlet Mass Rate (g/hr)	Percent Recovery
Ash Fed Compounds														
Cd	470	0	2.35	1.73	73.6	1.28	1.34	104.7	11.7	4.56	39.0	5.33	4.25	79.7
Cr	144	0	0.718	0.697	97.1	0.392	0.441	112.5	3.59	1.13	31.5	1.63	1.5	92.0
Pb	4865	0	24.3	20	82.3	13.2	14.5	109.8	121	49.2	40.7	55.2	49.7	90.0
Hg	47.3	0	0.236	0.199	84.3	0.129	0.145	112.4	1.18	0.548	46.4	0.536	0.464	86.6
Ash and Salt Sol'n Fed Compounds														
Bi	160	43.1	43.9	15.3	34.9	43.5	10.1	23.2	47.1	22	46.7	44.9	13.1	29.2
Cu	740	26.3	30	11.2	37.3	28.3	8.14	28.8	44.8	17.3	38.6	34.7	10.7	30.8
Mg	8400	42.7	84.6	5.25	6.2	65.6	2.76	4.2	252	3.14	1.2	138	5.13	3.7
As	191	30.1	31.1	15.4	49.5	30.6	13.4	43.8	34.9	17.7	50.7	32.3	17	52.6
Sr	290	41.4	42.8	7.19	16.8	42.2	5.36	12.7	48.6	4.23	8.7	44.7	2.91	6.5

[a] Constant throughout tests.
[b] Total feed = Metals from ash + metals in salts solutions.
[c] low/low: MSW ash feed = 11 lbs/hr, $Al2(SO_4)2$ feed = 6 lbs/hr, runs 4, 7, and 8.
low/high: MSW ash feed = 6 lbs/hr, $Al2(SO_4)2$ feed = 11 lbs/hr, runs 2, and 5.
high/low: MSW ash feed = 55 lbs/hr, $Al2(SO_4)2$ feed = 25 lbs/hr, run 6.
high/high: MSW ash feed = 25 lbs/hr, $Al2(SO_4)2$ feed = 55 lbs/hr, runs 3 and 7.

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The poor recoveries observed for some of the spiked metals are believed to be due to loss or drop out of metals in the incinerator or the duct work prior to the inlet sampling point. John Zink personnel reported some buildup of slag and particulate in the incinerator upon completion of the testing.

3.2.2 Outlet to the Control Device

The outlet metals results are presented as concentrations adjusted to 7 percent O_2 in Table 3-8 and as mass rates in Table 3-9. For Runs 2 and 3, it should be noted that the mass rates are based on the slipstream flow rate.

Test results presented in Table 3-8 generally show similar control system outlet concentrations for each of the target metals for all eight test runs. Any observed differences in metals concentrations between test runs and between operating conditions are not statistically significant. The highest concentrations were observed for lead (30.5 to 245 ug/dscm) and the lowest were for strontium (2.6 to 12 ug/dscm) and magnesium (not detected). The single apparent outlier in the data presented in Table 3-8 is the Run 8 outlet concentration of 512 ug/dscm for chromium. [The cause for this unreasonably high value is being investigated.]

3.2.3 Metals Removal Efficiencies

Metals removal efficiencies are presented in Table 3-10. The removal efficiencies were calculated based on mass rates except for Runs 2 and 3 which were calculated using inlet and outlet concentrations adjusted to 7 percent oxygen. For the scrubber, the removal efficiencies ranged from 98 to 99 percent for all of the target metals, except mercury. Removal efficiencies for mercury ranged from 47 to 86 percent.

TABLE 3-8. SUMMARY OF THE OUTLET METALS FLUE GAS CONCENTRATION FOR THE JOHN ZINK TEST PROGRAM

TEST CONDITION	Low/high	High/high	Low/low	Low/high	High/low	High/high	Low/low	Low/low
	CONCENTRATION IN THE FLUE GAS[a] (ug/dscm adjusted to 7 % O2)							
	ESP		Hydro-Sonic Scrubber					
PARAMETER	RUN 2	RUN 3	RUN 4	RUN 5	RUN 6	RUN 7	RUN 8[b]	RUN 9
Arsenic	6.51	6.94	28.3	19.0	9.92	7.14	22.6	24.4
Bismith	[389]	[332]	89.0	108	96.9	[87.3]	91.5	[77.0]
Cadmium	31.3	14.5	12.5	17.7	27.1	15.7	17.7	13.9
Chromium	14.6	16.6	8.23	12.7	12.1	13.8	512	4.35
Copper	74.9	24.9	70.9	79.4	68.6	25.8	67.5	34.3
Lead	30.5	119	142	180	245	145	211	159
Magnesium	[486]	[415]	[111]	[108]	[108]	[109]	[101]	[96.2]
Mercury	161	299	77.9	51.7	53.5	113	22.8	25.7
Strontium	8.75	11.6	5.22	7.24	3.37	2.63	5.74	6.86

aBrackets indicate that the metal was not detected. The value in the bracket is the minimum detection limit.
bThe chromium value for Outlet-Run 8 is considered suspect due to its very high value.

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TABLE 3-9. SUMMARY OF THE OUTLET MASS RATES FOR THE JOHN ZINK TEST PROGRAM.

TEST CONDITION	Low/high	High/high	Low/low	Low/high	High/low	High/high	Low/low	Low/low
	MASS RATE (mg/hr)[a]							
	ESP		Hydro-Sonic Scrubber					
Parameter	RUN 2[b]	RUN 3[b]	RUN 4	RUN 5	RUN 6	RUN 7	RUN 8	RUN 9
Arsenic	0.297	0.354	40.4	27.3	13.5	10.3	31.8	37.6
Bismith	[39.1]	[16.9]	127	155	132	[126]	129	[119]
Cadmium	1.43	0.741	17.8	25.4	36.9	22.6	24.9	21.4
Chromium	0.664	0.847	11.7	18.3	16.5	19.9	721	6.71
Copper	3.41	1.27	101	114	93.2	37.1	95.0	52.9
Lead	1.39	6.10	203	259	333	209	296	245
Magnesium	[48.8]	[21.2]	[159]	[155]	[146]	[157]	[143]	[148]
Mercury	7.35	15.2	111	74.2	72.7	162	32.1	39.6
Strontium	0.398	0.593	7.45	10.4	4.58	3.78	8.07	10.6

[a] Brackets indicate that the metal was not detected. Values in brackets are minimum detection limits.

[b] The outlet mass rates for Runs 2 and 3 are calculated from the slipstream flow rate which is about 10 percent of the total quench exhaust flow rate.

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TABLE 3-10. METALS REMOVAL EFFICIENCY ACROSS THE CONTROL DEVICE

CONTROL DEVICE	REMOVAL EFFICIENCY ACROSS THE CONTROL DEVICE (%)								
	ESP		SCRUBBER						
PARAMETER	RUN 2	RUN 3	RUN 4	RUN 5	RUN 6	RUN 7	RUN 8	RUN 9	AVERAGE
Arsenic	99.95	99.93	99.81	99.78	99.92	99.95	99.60	99.77	99.84
Bismith	99.99	99.99	99.49	98.76	99.40	99.99	98.31	99.99	99.49
Cadmium	97.39	99.48	99.07	98.13	99.19	99.51	98.27	98.83	98.73
Chromium	94.31	98.06	98.54	96.96	98.54	98.91	(-46.32)[c]	99.16	97.78
Copper	99.22	99.66	99.55	97.99	99.46	99.67	98.41	98.92	99.11
Lead	99.79	99.64	99.12	98.01	99.32	99.61	97.86	98.94	99.04
Magnesium	99.99	ND[b]	99.99	99.99	99.99	99.99	99.99	99.99	99.99
Mercury	(-31.73)[a]	12.06	47.15	52.43	86.74	64.63	83.91	78.89	53.23
Strontium	99.86	99.06	99.90	99.71	99.89	99.91	99.75	99.90	99.75

[a] Negative value indicates that removal is not statistically different from zero.

[b] ND indicates that the compound was not detected at either the inlet or outlet.

[c] Value is considered suspect and is under investigation. Value is not included in average.

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Metals removal efficiencies across the ESP were greater than 99 percent for all of the target metals, again with the exception of mercury. The data for mercury shows removal efficiencies ranging from essentially zero to approximately 12 percent.

3.2.4 Ratio of Metals to Particulate

The metals-to-particulate ratio is defined as the mass of a particular metal present per unit mass of particulate matter (mg of metal per g of particulate). The ratios are calculated by dividing the metals concentration (ug/dscm) by the particulate concentration (mg/dscm). In general, this ratio will be higher for smaller particles because small particles have higher surface area per unit mass and metals that have been vaporized in the combustion zone will condense on a particle in proportion to the available surface area. If a control device is removing large particles and allowing the smaller particulate to escape, the metals-to-particulate ratio will generally increase across the control system.

Metals-to-particulate ratios for inlet and outlet samples are presented in Table 3-11. Comparison of inlet and outlet metals-to-particulate ratios for the ESP (Runs 2 and 3) generally shows enrichment of mercury across the control device. The remaining metals, however, show either an increase or no significant change in metals-to-particulate ratio across the ESP. The data showing little or no change in metals-to-particulate ratio suggest that the ESP was removing both large and fine particles equally well.

Comparison of metals-to-particulate ratios in Table 3-11 for the Hydro-Sonic scrubber shows significant enrichment of lead, mercury, copper, and bismuth, as well as slight enrichment of cadmium and chromium across the control device. These results suggest that particles escaping control by the scrubber are largely the finer or sub-micron particles.

TABLE 3-11. RATIO OF METALS TO PARTICULATES AT THE CONTROL DEVICE INLET FOR THE JOHN ZINK PERFORMANCE TRIALS

PARAMETER	METALS/PARTICULATE RATIO[a] (mg metal per gram of particulate)							
	ESP		Hydro-Sonic Scrubber					
	RUN 2	RUN 3	RUN 4	RUN 5	RUN 6	RUN 7	RUN 8	RUN 9
					INLET			
Arsenic	6.14	1.45	5.17	3.88	1.81	1.56	1.61	5.06
Bismith	3.30	0.214	6.01	3.86	2.24	1.82	1.53	4.09
Cadmium	0.568	0.427	0.464	0.421	0.466	0.346	0.290	0.555
Chromium	0.121	0.130	0.194	0.186	0.115	0.137	0.100	0.241
Copper	4.55	1.11	5.46	1.76	1.76	0.846	1.21	1.49
Lead	6.90	5.10	5.57	4.02	5.02	3.97	2.80	7.00
Magnesium	1.89	ND	1.69	0.351	0.320	0.385	0.622	1.72
Mercury	0.058	0.052	0.051	0.048	0.056	0.034	0.040	0.057
Strontium	3.06	0.188	1.86	1.12	0.432	0.308	0.664	3.21
					OUTLET			
Arsenic	0.394	0.111	2.74	2.27	1.04	0.458	1.75	4.31
Bismith	ND	ND	8.62	12.9	10.2	ND	7.10	ND
Cadmium	1.89	0.231	1.21	2.11	2.85	1.01	1.37	2.46
Chromium	0.882	0.265	0.797	1.52	1.27	0.886	39.8	0.769
Copper	4.53	0.397	6.87	9.51	7.20	1.66	5.24	6.07
Lead	1.85	1.90	13.7	21.6	25.7	9.31	16.3	28.1
Magnesium	ND	ND	ND	ND	ND	ND	ND	ND
Mercury	9.76	4.76	7.54	6.19	5.62	7.23	1.77	4.54
Strontium	0.529	0.185	0.506	0.867	0.354	0.169	0.445	1.21

[a]ND = not detected.

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3.3 PARTICLE SIZE DISTRIBUTIONS

The objective of the particle size distribution (PSD) analysis was to 1) determine the effect of changes in material feed rates and composition on particle size and 2) document the size distribution of particles entering the air pollution control system.

Due to the high grain loading at the quench pot inlet sampling location, an Anderson high capacity stack sampler (HCSS) heavy grain loading impactor was used. This sampler separates particles into four size ranges. Each size range is typically represented by the 50 percent cut point value (Dp_{50}). This value represents the aerodynamic diameter of a particle which has been empirically determined to be removed with 50 percent efficiency for that respective PSD stage at the given gas conditions (temperature, viscosity, flow, etc.). Cut points are determined for the first three stages and the remaining smaller particles are removed by the back-up filter or fourth stage.

Table 3-12 shows the results of the PSD test runs conducted at the inlet. Size range data for each run are presented in Table 3-12, along with the mass median particle diameter (MMD). The MMD is the particle size where half the particulate mass is associated with larger particles and half the mass is associated with smaller size particles. This value is determined as shown in Appendix A.3.

Figures 3-1 and 3-2 present plots of the cumulative mass fraction of particles less than a given particle size at the low and high particulate loading conditions, respectively. Data presented in Figure 3-1 for the low particulate loading tests show a distinct difference between test Runs 2 and 5 (low/high) and test Run 4 (low/low). As expected, there is a larger fraction of smaller particles in the low/high samples. This observation is confirmed by comparing the MMD of 23.9 microns for the low/low condition versus a MMD of 3.5 microns for the low/high condition shown in Table 3-12.

TABLE 3-12. SUMMARY OF INLET PARTICLE SIZE DISTRIBUTION RESULTS

Run Number/ Test Condition	Impactor Stage	Cutsize (microns)	Size Range (microns)	Geometric Midpoint (microns)	Mass Fraction Less Than Cutsize	Mass Mean Diameter (microns)	Isokinetic Sampling Rate (%)
Run 4 Low/Low	1	15.4	>15.4	27.8	0.45	23.9	92.1
	2	8.64	15.4 - 8.64	11.5	0.36		
	3	2.99	8.64 - 2.99	5.08	0.25		
Run 2 Low/High	1	15.9	>15.9	28.2	0.68	3.05	81.4
	2	9.67	15.9 - 9.67	12.4	0.63		
	3	3.49	9.67 - 3.49	5.81	0.53		
Run 5 Low/High	1	15.5	>15.5	27.8	0.85	3.92	87.5
	2	8.36	15.5 - 8.36	11.4	0.70		
	3	2.85	8.36 - 2.85	4.88	0.43		
Run 6 High/Low	1	15.8	>15.8	28.1	0.50	14.7	87.2
	2	8.91	15.8 - 8.91	11.9	0.43		
	3	3.05	8.91 - 3.05	5.21	0.28		
Run 7 High/High	1	15.0	>15.0	27.3	0.57	10.0	106
	2	7.83	15.0 - 7.83	10.8	0.46		
	3	2.60	7.83 - 2.60	4.51	0.16		

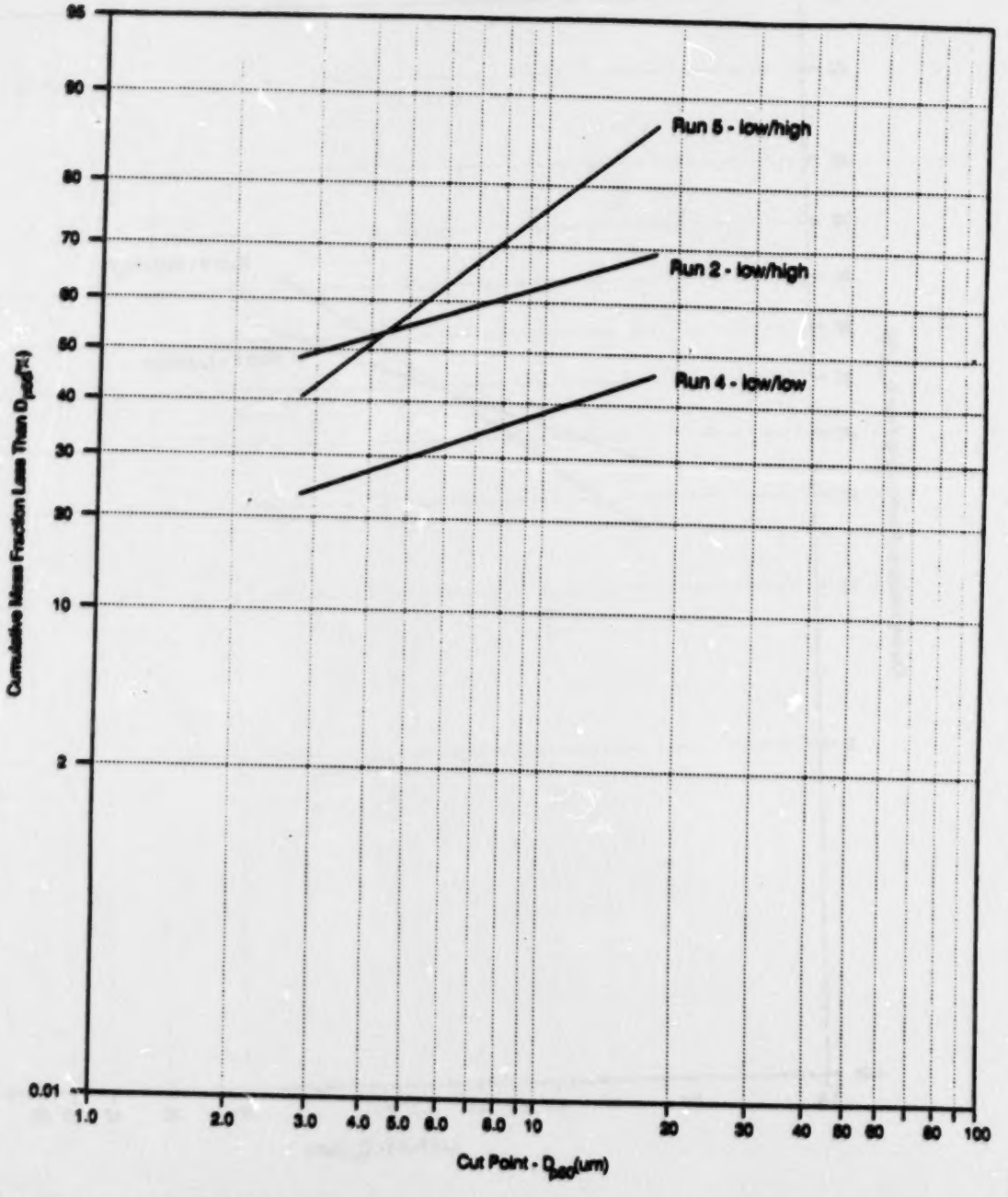


Figure 3-1. PSD Composite Curves Generated from Inlet Testing Data at Low Grainloading Conditions, John Zink Research Co., Tulsa, OK (April 1989)

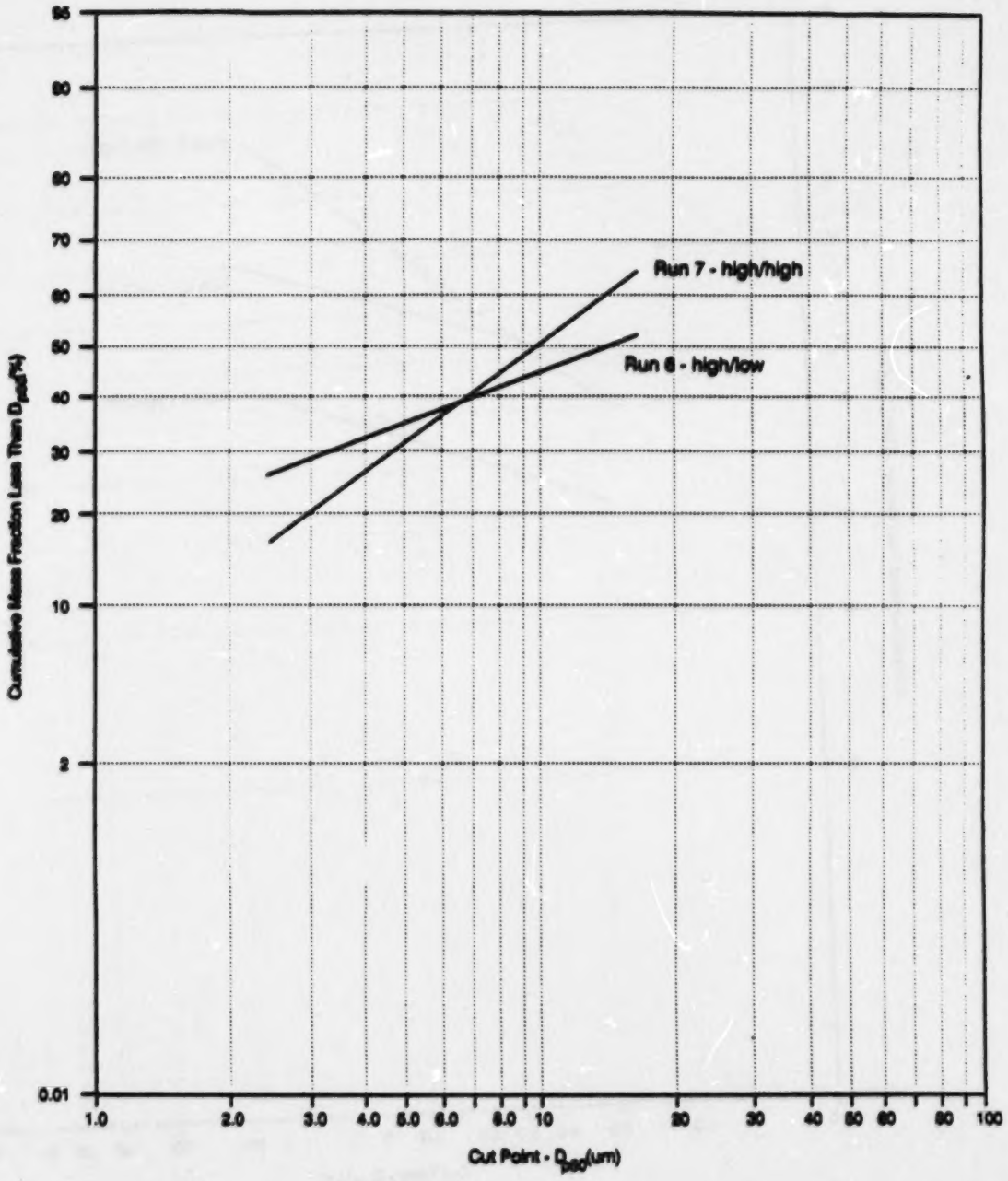


Figure 3-2. PSD Composite Curves Generated from Inlet Testing Data at High Grainloading Conditions, John Zink Research Co., Tulsa, OK (April 1989)

As shown in Figure 3-2, particle size results for the high particulate loading tests suggest that there is no apparent difference in the proportion of smaller particles for the high/high test condition compared to the high/low test condition. However, a comparison of the average MMD of 10 microns for the high/high test versus a MMD of 14.7 microns for the high/low test, increased proportion of smaller particles at the high/high condition. The difference between the high fraction of fine particles condition and the low fraction of fine particles condition is much smaller for the high particulate loading case (10 vs. 14.7 microns) than for the low particulate loading case (23.9 vs. 3.5 microns).

No data are reported in this section for Runs 1 and 3 because of a high isokinetic sampling rate for Run 1 and a leak in the final particulate filter during Run 3.

3.4 HYDROCHLORIC ACID (HCl) RESULTS

Sampling for HCl removal across the Hydro-Sonic scrubber system was performed during the last four test runs. Three runs were performed at both the inlet and outlet (10-12), and the fourth was completed at the outlet only (13).

Test results for the HCl sampling are shown in Table 3-13. HCl emissions were below the analytical detection limit (2 parts per million by volume, ppmv) for all outlet samples except Run 12. The HCl emission rate for Run 12 was 0.056 lb/hr. Removal efficiencies for HCl based on comparison of inlet and outlet samples were >99.9 percent, >99.7 percent, and 99.2 percent for Runs 10, 11, and 12, respectively. Removal efficiencies based on carbon tetrachloride feed rates of 13.45 lb/hr were 99.5 percent for Run 12 and >99.9 percent for the remaining three runs.

TABLE 3-13. SUMMARY OF HCl SAMPLING RESULTS

Run Number	Gas Flow Rate acfm	Gas Flow Rate dscfm	% Oxygen	HCl Emissions ppmV	HCl Emissions lb/hr	HCl Removal Efficiency (percent)
Inlet - 10	3551	830	5.3	2048	9.647	
Inlet - 11	3556	821	5.8	1366	3.362	
Inlet - 12	3565	801	5.1	1503	6.835	
Inlet - Average	3557	817	5.4	1693	6.615	
Outlet - 10	2881	967	7.0	<1.83	<0.010	>99.9
Outlet - 11	2842	931	6.5	<1.90	<0.010	>99.7
Outlet - 12	2891	922	7.1	10.80	0.056	99.2
Outlet - 13	2870	891	6.2	<1.99	<0.010	
Outlet - Average	2871	940	6.9	<4.84	<0.025	>99.6

SECTION 4

SAMPLING LOCATIONS AND PROCEDURES

Sampling locations are discussed in Section 4.1 and sampling methods and procedures are discussed in Section 4.2.

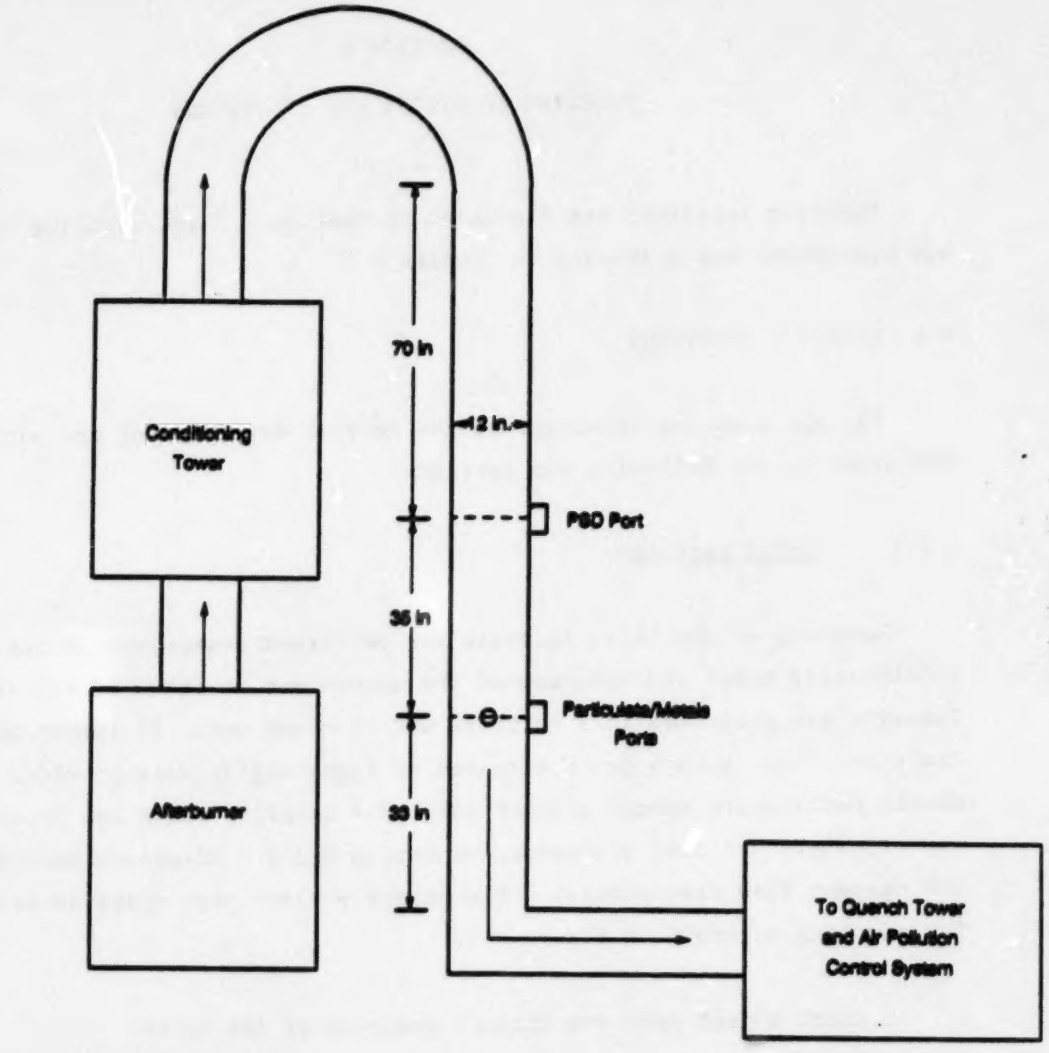
4.1 SAMPLING LOCATIONS

The gas sampling locations at the control device inlet and outlet are discussed in the following two sections.

4.1.1 Inlet Location

Sampling at the inlet location was performed downstream of the flue gas conditioning tower and upstream of the quench pot as shown in Figure 2-1. Sampling was performed in a vertical run of round duct, 12-inches in diameter. Two, 4-inch ports situated at right angles were provided for metals/particulate sample acquisition. The sampling plane was located approximately 8.7 duct diameters downstream and 2.7 diameters upstream from the nearest flow disturbances. Six points on each port traverse were used for sampling as shown in Figure 4-1.

A third 4-inch port was located upstream of the inlet particulate/metals sampling plane and used for particle size sample acquisition. The nearest flow disturbances were 5.8 diameters downstream and 4.0 diameters upstream. A preliminary six-point traverse was completed at the PSD sample location as shown in Figure 4-2. The measured velocity



Particulate/Metals Traverse Points

Point No.	Distance (in)
1	1
2	1.8
3	3.8
4	8.5
5	10.3
6	11

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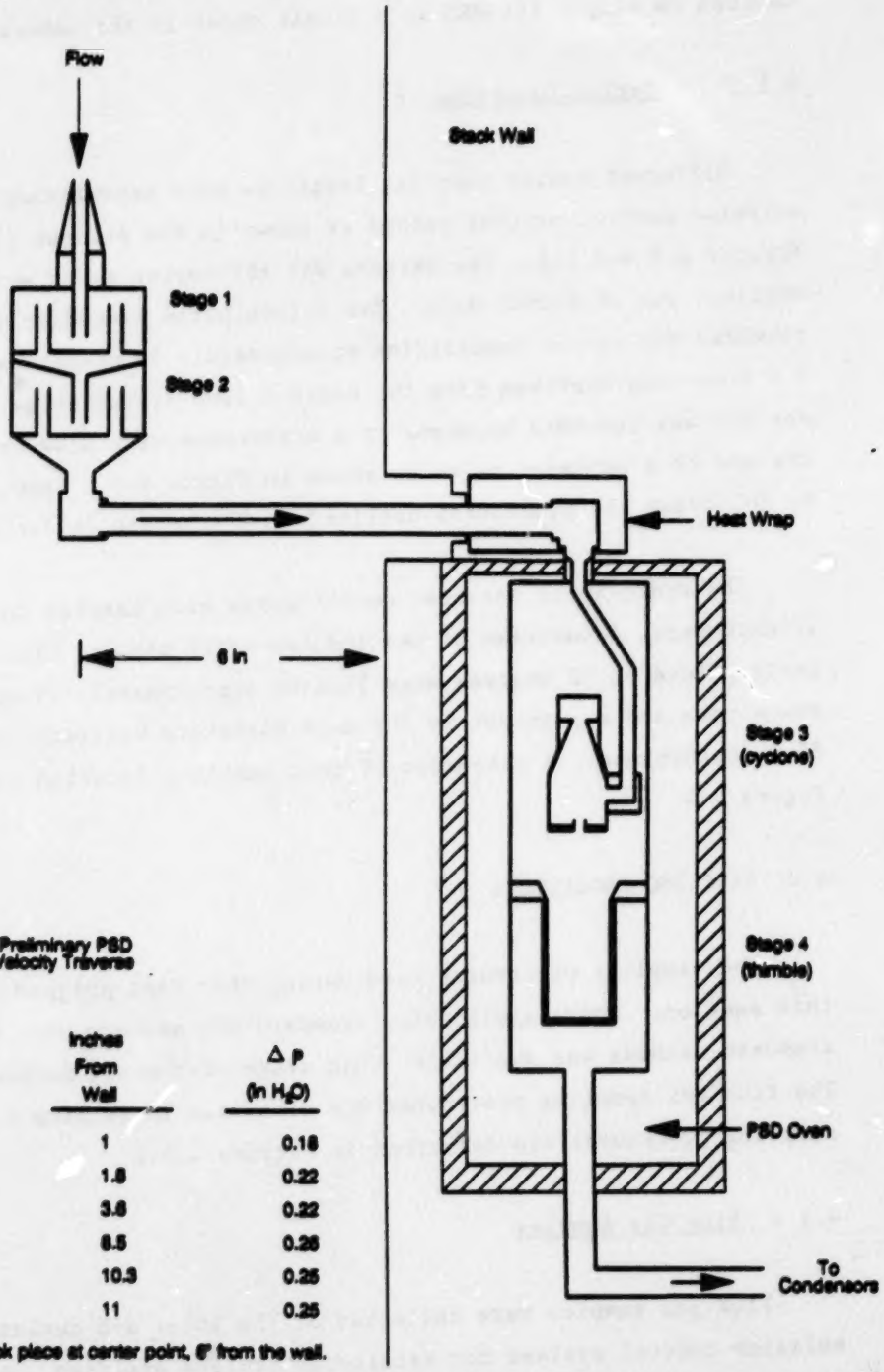
Figure 4-1. Inlet PSD and Particulate/Metals Sampling Locations, John Zink Research Co, Tulsa, OK (April 1989)



Preliminary PSD
Velocity Traverse

Point No.	Inches From Wall	Δ P (in H_2O)
1	1	0.18
2	1.8	0.22
3	3.8	0.22
4*	6.5	0.26
5	10.3	0.25
6	11	0.25

*PSD sampling took place at center point, 6" from the wall.

Figure 4-2. Inlet PSD Sampling Configuration Using the Anderson HCSS High Grainloading Impactor, John Zink Research Co, Tulsa, OK (April, 1989)

heads ranged from 0.18" H_2O to .26 H_2O. The average velocity head of 0.23" H_2O was bracketed by the two center most points. It was, therefore, decided to sample for PSD at a single point in the center of the duct.

4.1.2 Outlet Locations

Different outlet sampling locations were established for each of the emission control systems tested as shown in the process flow diagrams in Figures 2-1 and 2-3. The Beltran Wet-ESP outlet gases were sampled in a vertical run of 8-inch duct. Two 3-inch ports placed at 90 degrees were provided for sample acquisition approximately 10 diameters downstream and 3.8 diameters upstream from the nearest flow disturbances. The gas flow to the ESP was provided by means of a slipstream with flow being controlled by the use of a dampener valve as shown in Figure 4-3. Sampling was completed by following the procedures outlined in EPA Method 2A for small ducts.

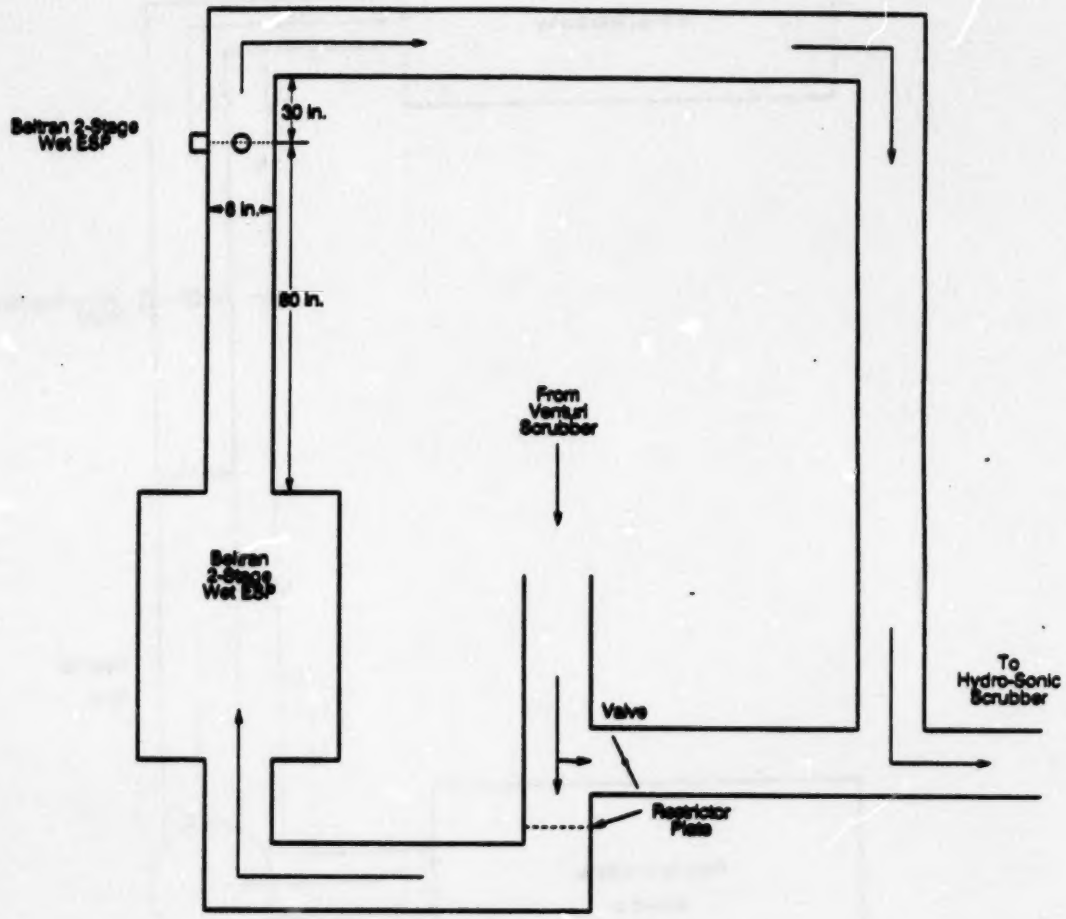
The Hydro-Sonic scrubber outlet gases were sampled in a vertical run of 17-inch duct, downstream of the induced draft blower. Two 4-inch sampling ports placed at 90 degrees were located approximately 18 duct diameters downstream and approximately 7.5 duct diameters upstream from the nearest flow disturbance. A schematic of this sampling location is shown in Figure 4-4.

4.2 SAMPLING PROCEDURES

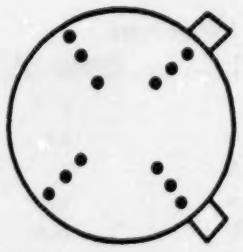
The sampling procedures used during this test program are described in this section. Where applicable, standard EPA methods were employed. If no standard methods was available, then state-of-the-art methods was applied. The flue gas sampling procedures are discussed in Section 4.2.1 and process sampling procedures are described in Section 4.2.2.

4.2.1 Flue Gas Samples

Flue gas samples were collected at the inlet and outlets of the emission control systems for metals/particulate analyses. Additional flue



Particulate/Metals Traverse Points



Point No.	(in.)
1	1.0
2	1.2
3	2.4
4	5.6
5	6.8
6	7.0

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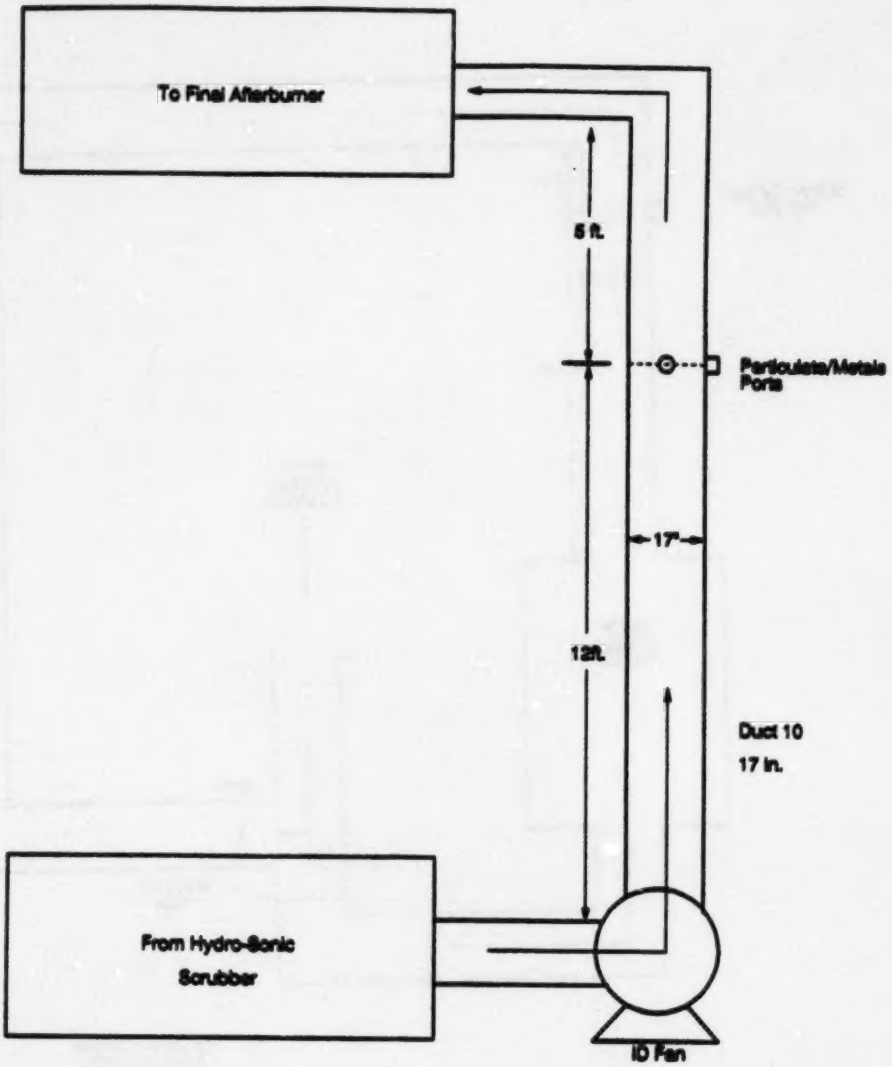
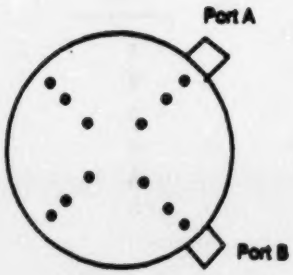
Figure 4-3. Outlet Particulate/Metals Sampling Location for the Venturi Scrubber/Wet ESP Performance Trials, John Zink Research Co., Tulsa, OK (April, 1989)





Traverse Points

Point No.	Distance (in.)
1	1
2	2.5
3	5
4	12
5	14.5
6	16

21900SR

Figure 4-4. Outlet Metals/Particulates Sampling Location for the Hydro-Sonic Scrubber Performance Trials, John Zink Research CO, Tulsa, OK (April 1989)

gas samples were taken at the inlet for PSD analyses. Each type of flue gas sample to be collected during this test program is described in detail in the following sections.

4.2.1.1 Particulate and Metals Sampling Method

Sampling for total particulate matter, toxic metals and non-toxic metals was conducted using a modified version of the Method 5 sampling train. This method, entitled "Methodology for the Determination of Trace Metal Emissions in Exhaust Gases from Stationary Source Combustion Processes"(1), has been proposed for acceptance by the U.S. EPA. A schematic of the sampling train is shown in Figure 4-5.

The front half of the sample train is identical to a Method 5 train. The nozzle, probe, and filter holder were constructed using borosilicate glass. A Teflon coated screen was used to support the filter. Both probe and filter holder were heated to 248 $\pm$ 25°F to prevent moisture condensation. A high purity glass fiber filter without organic binder and with a 99.95 percent collection efficiency on 0.3 micron dioctyl phthalate (DOP) smoke particles was used. Sampling was conducted for 120 minutes at the outlet to provide for an adequate sample volume. The grain loading at the inlet allowed a smaller volume of gas to be sampled and still insured collection of an adequate mass of particulate and metals. This resulted in a 60 minute test run which allowed for a PSD run to be completed in between port changes of particulate/metals. In this way, all inlet and outlet testing was conducted simultaneously.

The back half of the impinger train was modified to capture the metals in the vapor phase. The impingers were arranged as follows:

1) Empty knockout impinger (Modified Greenburg-Smith).

2) Greenburg-Smith impinger containing 100 ml of 5 percent HNO_3 and 10 percent H_2O_2 solution.

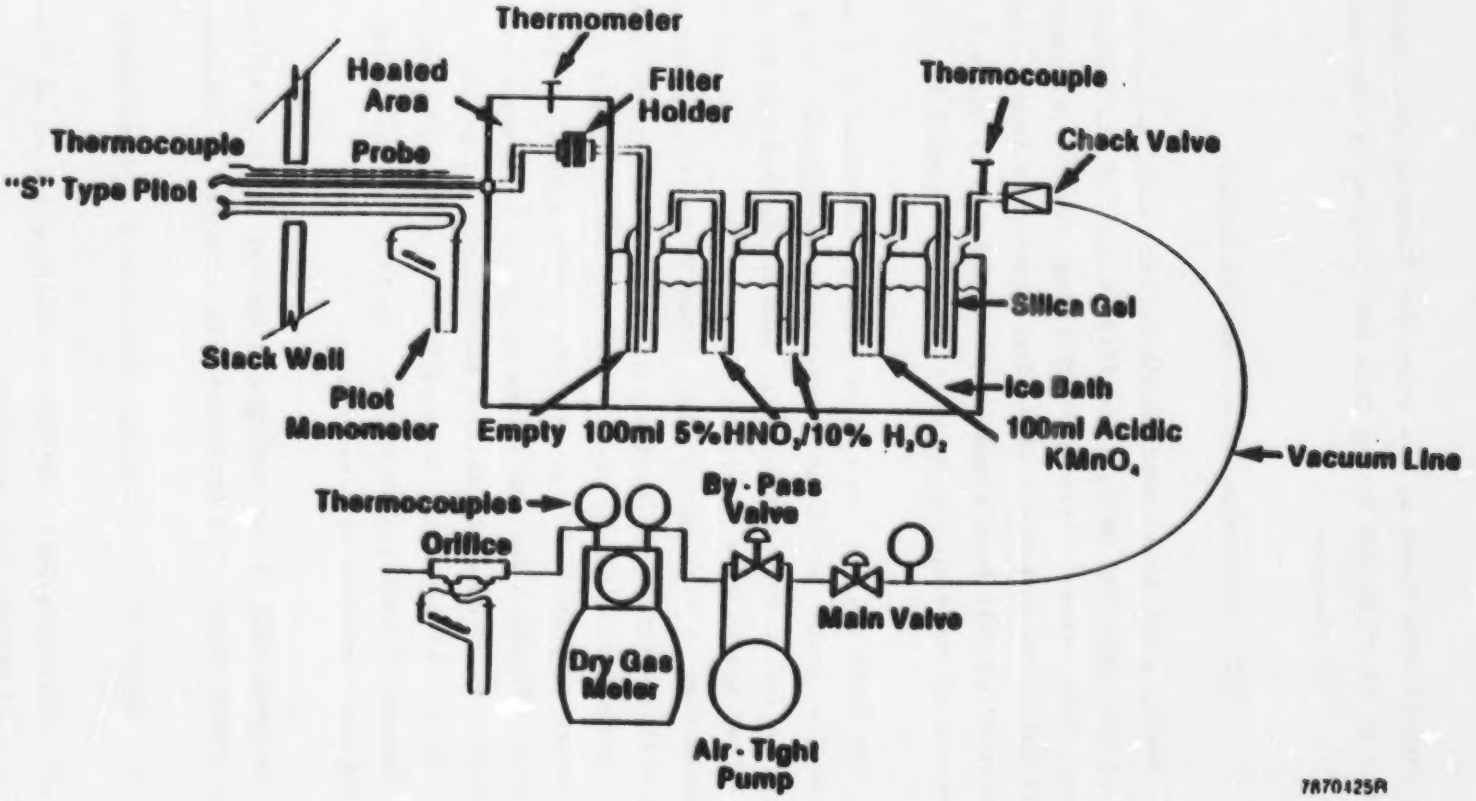


Figure 4-5. Schematic of the Toxic Metals Sampling Train

3) Same as 2 above.

4) Greenburg-Smith impinger containing 100 ml of acidic $KMNO_4$ solution.

5) Modified Greenburg-Smith impinger containing about 200 grams of indicating silica gel.

An ice bath was used to maintain an impinger exit temperature $\leq 68^{\circ}F$. All connections were made with leak tight, ground glass joints. The glassware used for the particulate/toxic metals train was cleaned according to the procedures outlined in Table 4-1.

The flue gas was withdrawn from the stack isokinetically. At the end of the test run, the train was disassembled into three parts: 1) probe, 2) filter and connecting glassware, and 3) impingers. Each part of the sample train was sealed to prevent sample loss or contamination. These parts of the sample train were then transferred to the field laboratory where they were recovered as shown in Table 4-2. A final weight for each impinger was also obtained during recovery for moisture determination. All sample containers were tared and final sample weights were determined and liquid levels marked so that it could determined if any sample was lost during transport. Caps with tiny holes drilled in them were used for sample container Number 4. The holes (#72 gauge) could allow continual venting to avoid pressure buildup in the sample bottle. No sample leakage was observed during transport of the samples.

4.2.1.2 Particle Size Distribution

Particle size distribution was determined at the outlet of the conditioning tower and prior to the quench pot. An Andersen HCSS particle sizing stack sampler was used. The Andersen HCSS is an in-stack, multistage, cascade impactor that measures the size distribution of particle emissions and total particulate mass concentration. A cascade impactor

TABLE 4-1. PARTICULATE/METALS GLASSWARE CLEANING PROCEDURES

NOTE: USE DISPOSABLE GLOVES AND ADEQUATE VENTILATION

1. Soak all glassware in hot, soapy water (Alconox®).
2. Rinse with tap water (X3).
3. Rinse with distilled, deionized water (X3).
4. Soak in 10 percent HNO_3 for 8 hours.
5. Rinse with distilled, deionized water (X3).
6. Rinse with acetone to dry.
7. Allow glassware to air dry in a contamination-free environment.
8. Cap glassware with paraffin film, rubber caps, or glass plugs.

X3 = Three times.

TABLE 4-2. SAMPLE RECOVERY COMPONENTS FOR THE PARTICULATE/METALS TRAIN

Component	Code	Item
Front Half		
1	PR-Acet	Acetone rinse of probe liner, nozzle and front half of filter housing using a nylon bristle brush with Teflon®-handle.
2	PR-HNO_3	0.1N nitric acid rinses of probe liner, nozzle, and front half of filter housing.
3	F	Filter.
Back Half		
4	IR-1	Contents of impingers 1-3 and rinses with HNO_3/H_2O_2 solution.
5	IR-2	50 mL aliquot from IR-1.
6	IR-3	Contents and rinses of impinger number 4. Rinse with 4 percent HCl.

classifies particles according to their aerodynamic diameter as opposed to the stokes or physical diameter.

The components of the sampling train are similar to an EPA Method 5 train except for the impactor which is attached to the probe. The particulate-laden flue gas was withdrawn isokinetically through the nozzle and pulled through the impactor. The gas was then drawn through a 1/2-inch steel probe to a series of condensers to remove any moisture prior to entering the pump and DGM.

The HCSS is structurally composed of two major components. The first component consists of the nozzle and the first two impaction chambers. The second component is made up of the cyclone (3rd stage) and the filter thimble housing assembly. When assembled in a straight line the entire unit is approximately 3 feet long. Because the inlet duct was only 12 inches in diameter, the HCSS was used in a "zig-zag" configuration was shown in Figure 4-2. This would not allow for in-stack placement of both components so an oven assembly was constructed to house the cyclone/filter assembly outside of the stack. Therefore, the first two stages received the sample gas at stack temperatures and in the back two stages, the sample gas temperature was controlled by the oven. Ideally, sampling should have been accomplished at a constant temperature throughout all four stages of the impactor. However, matching the two temperatures proved to be very difficult. Therefore, the stack temperature was used to calculate flow through stages one and two and the sample gas temperature at the impactor exit was used to determine flow through stages three and four. These flows were then used to calculate each stages repective cut point.

The impactor outlet gas temperature was monitored with a K-type thermocouple and controlled using variable power controllers wired to the oven heaters. The required sampling time was calculated on-site based on the particulate loading and the velocity profile measured. A preliminary velocity measurement and stack temperature were taken immediately before the

PSD run at the single, central traverse point, and used to calculate isokinetic sampling rates. A leak check was performed prior to the test on the back HCSS component (Stages 3 and 4). Anderson states that because there is no inherent pressure drop across the first two stages, a leak check need not be completed on these components. A post-test leak check could not be completed in order to maintain the integrity of the PSD sample.

After the test was completed the PSD was transferred to a recovery room where the unit was allowed to cool down. Upon dismantling, the particulate catches from Stages 1 through 3 were brushed onto tared aluminum foil pieces so that a desicated weight could be determined at a later date. The thimble filter was also placed in a tared aluminum foil piece for future weighing. The first three stages were then rinsed separately with acetone, dried and weighed to a constant value. The rinse weight was then added to the brushed sample weight to determine total sample weight of each respective stage.

4.2.1.3 HCl Sampling Method

Flue gases were sampled for HCl determinations using the back half of the particulate trains for Runs 10-13. The sampling train consisted of an EPA Method 5 sampling system that had been modified to allow collection of hydrochloric acid gases in the impinger portion (back half) of the sampling train as shown in Figure 4-6. The following modifications were made:

- The first and second impingers were charged with 0.1N sulfuric acid instead of water;
- The third impinger was left empty for condensate collection; and
- A fourth impinger contained silica gel.

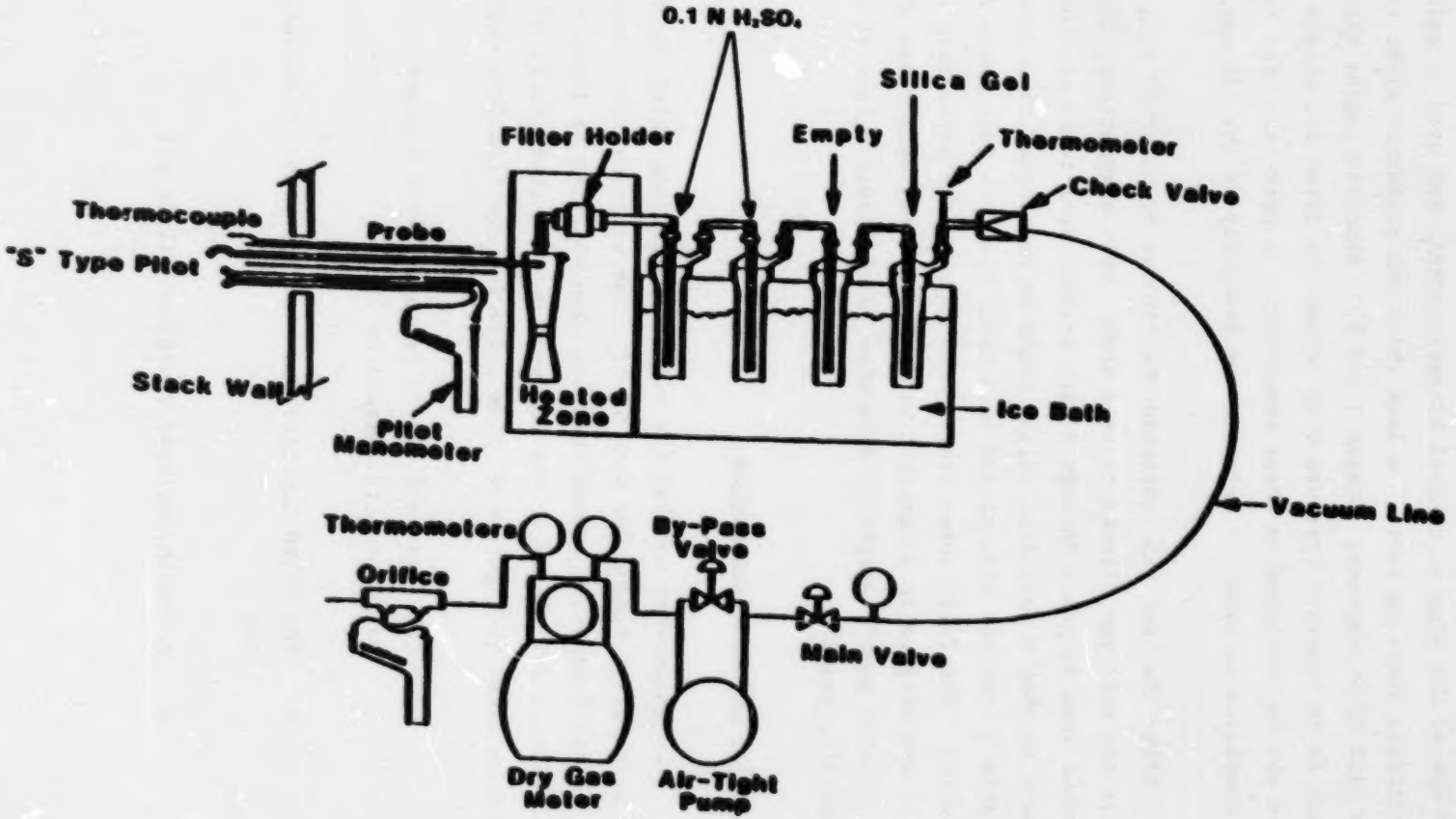


Figure 4-6. Components of the Particulate/HCl Sampling Train

Sampling proceeded according to EPA Method 5 guidelines. The changes made in this sampling train were based on the draft method published by the EMSL division of the U.S. EPA in July, 1988 titled "Draft Method for the Determination of HCl Emissions from Municipal and Hazardous Waste Incinerators."

4.2.1.4 EPA Methods 1,2,3 and 4

The standard methods used to determine the volumetric flow rate content, molecular weight and exhaust gas moisture are described in the following paragraphs.

The volumetric gas flow rate was determined during this program using procedures described in EPA Method 2. Based on this method, flows were calculated by multiplying the cross-sectional area of the duct times the average velocity of the exhaust gas.

The average exhaust gas velocity is calculated from the average pitot tube differential pressure (P), the average flue gas temperature, wet molecular weight, and the absolute static pressure. Temperature and differential pressure data were obtained by traversing the duct. The number of sampling points required to measure the average gas velocity was determined using the procedures outlined in EPA Method 1. The number of sampling points and their distance from the duct wall is a function of the proximity of the sampling location to its nearest upstream and downstream flow disturbance.

Temperature and pressure profile data were measured at each of the sampling points using an S-type pitot tube and K-type thermocouple. An oil manometer of the proper range was used to measure the pressure differential across the S-type pitot. The inlet location and the Hydro-Sonic scrubber outlet location used 0-1" H_2O inclined/1-10" H_2O vertical manometer. The Beltran ESP outlet location required the use of an expanded scale, 0-25" H_2O inclined manometer. A bourden absolute pressure gauge was used to obtain

barometric pressure readings at least once a day. The static gas pressure at the emission control device inlet and outlet was measured by disconnecting one side of the S-type pitot and then rotating the pitot so that it is perpendicular to the gas flow.

The integrated sampling technique described in EPA Method 3 was used to obtain a composite exhaust gas sample for fixed gas (O_2, CO_2) analysis. A small diaphragm pump and a stainless steel probe was used to extract a single point flue gas sample which was collected in a Tedlar® bag. Moisture was removed from the gas sample by an ice bath condenser so that the fixed gas analysis was on a dry basis. The composition of the gas sample was determined using an Orsat analyzer. If more than 6 passes were required to obtain a constant ($\leq$ 0.3 percent difference, absolute) reading for either O_2 or CO_2, the appropriate absorbing solution was replaced.

The moisture content of the flue gas was determined using the methodology described in EPA Method 4. Based on this method, a known volume of particulate-free gas is pulled through a chilled impinger train. The quantity of condensed water is determined gravimetrically and then related to the volume of gas sampled to determine the moisture content.

4.2.2 Process Samples

Samples of the MSW ESP fly ash injected into the afterburner were collected during the test periods. The ash was stored in 55 gallon drums prior to being injected into the afterburner. Two grab samples of ash were collected. The ash was analyzed for metals and also was archived.

SECTION 5.0

ANALYTICAL PROCEDURES

Laboratory activities for this program included analyses for particulate, particulate size distribution, metals, and hydrochloric acid (HCl). Each of the methods is described briefly in the sections below.

5.1 PARTICLE SIZE DISTRIBUTION

Recovery of the PSD sample was performed as explained in Section 4.2.1.2. The brushed PSD fractions were immediately placed in a desiccator upon arrival at Radian's Perimeter Park laboratory. The volume of the acetone rinses was measured and each rinse was placed in a tared beaker and allowed to evaporate in a hood. The dried beakers were also placed in a desiccator so that additional moisture could be removed. Both types of samples were then weighed periodically until a constant weight was achieved. The brushed fraction and rinse fraction were summed and incorporated into the final calculations as shown in Appendix A.3.

5.2 TOTAL PARTICULATE MATTER

The quantity of particulate matter recovered was determined gravimetrically. Both the filter and the front half acetone rinses were dried and weighed to a constant weight on a five place analytical balance. The resulting net weights were then incorporated into the grain loading determination as shown in Appendix A.1.

5.3 METALS ANALYSES

Concentrations of cadmium, chromium, copper, bismuth, strontium, and magnesium in the toxic metals train samples were determined by SW-846 Method 6010, which uses an inductively coupled argon plasma (ICAP) technique. Lead, arsenic and mercury concentrations in the samples were determined by SW-846 Methods 7421, 7060 and 7470, respectively. The lead, arsenic and mercury methods involve the use of an atomic absorption (AA) spectrometer. The digestion and analysis scheme is shown in Figures 5-1 and 5-2.

5.4 HCl ANALYSIS

Concentrations of HCl were determined by analyzing the H_2SO_4 impinger solutions for chloride ions (Cl^-) concentration. This was accomplished using ion chromatography (IC). A multipoint calibration was completed prior to and following injections of the samples in order to account for any instrument drift which may occur.

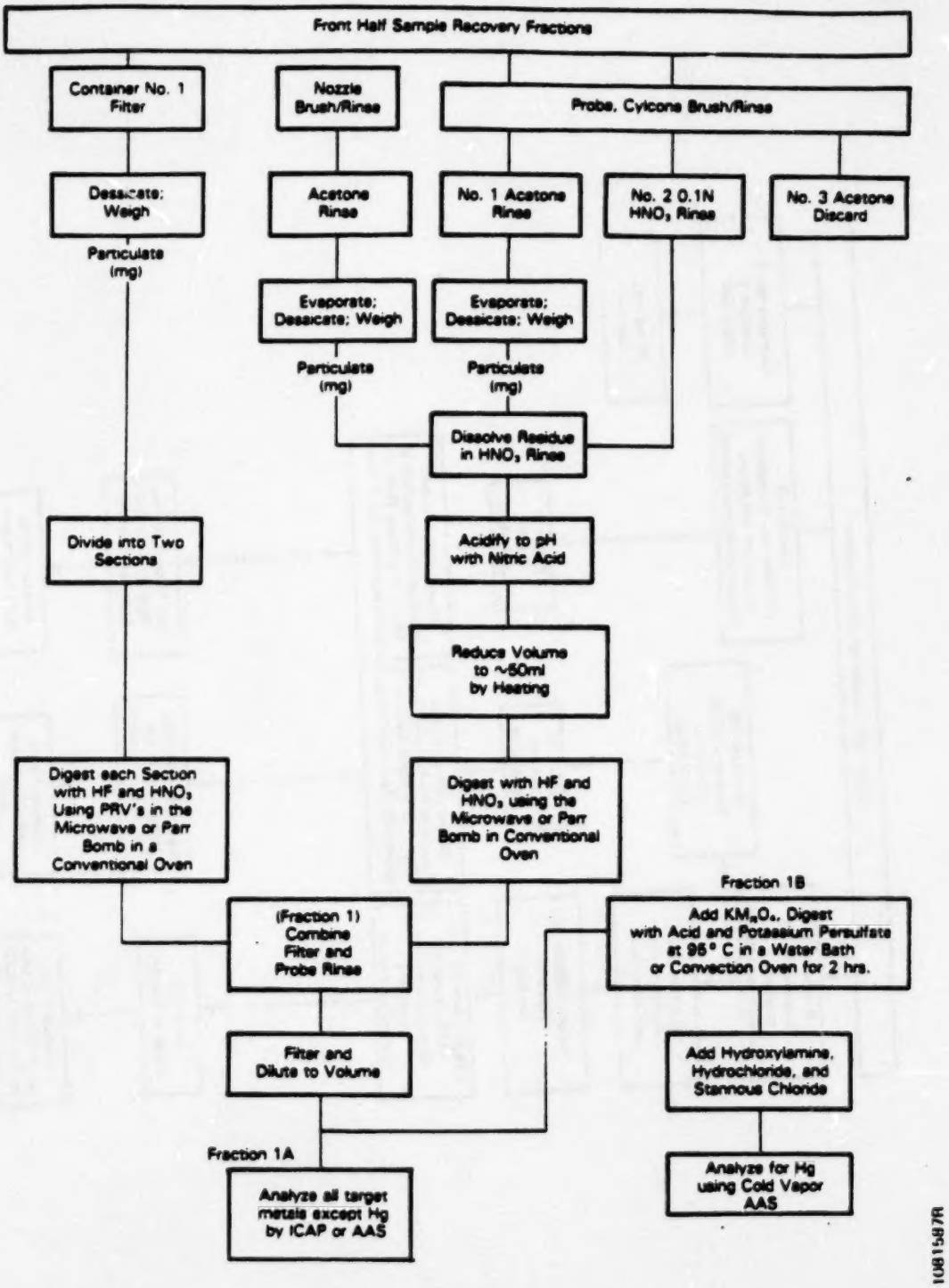

Front Half Sample Recovery Fractions
Container No. 1 Filter
Nozzle Brush/Rinse
Probe, Cyclone Brush/Rinse
Desiccate; Weigh
Acetone Rinse
No. 1 Acetone Rinse
No. 2 0.1N HNO3 Rinse
No. 3 Acetone Discard
Particulate (mg)
Evaporate; Desiccate; Weigh
Evaporate; Desiccate; Weigh
Particulate (mg)
Particulate (mg)
Dissolve Residue in HNO3 Rinse
Divide into Two Sections
Acidify to pH with Nitric Acid
Reduce Volume to ~50ml by Heating
Digest each Section with HF and HNO3 Using PRV's in the Microwave or Parr Bomb in a Conventional Oven
Digest with HF and HNO3 using the Microwave or Parr Bomb in Conventional Oven
Fraction 1B
(Fraction 1) Combine Filter and Probe Rinse
Add KMnO4. Digest with Acid and Potassium Persulfate at 95° C in a Water Bath or Convection Oven for 2 hrs.
Filter and Dilute to Volume
Add Hydroxylamine, Hydrochloride, and Stannous Chloride
Fraction 1A
Analyze all target metals except Hg by ICAP or AAS
Analyze for Hg using Cold Vapor AAS
108158?R

Figure 5-1. Digestion and Analysis Scheme for Toxic Metal Train Components - Front Half

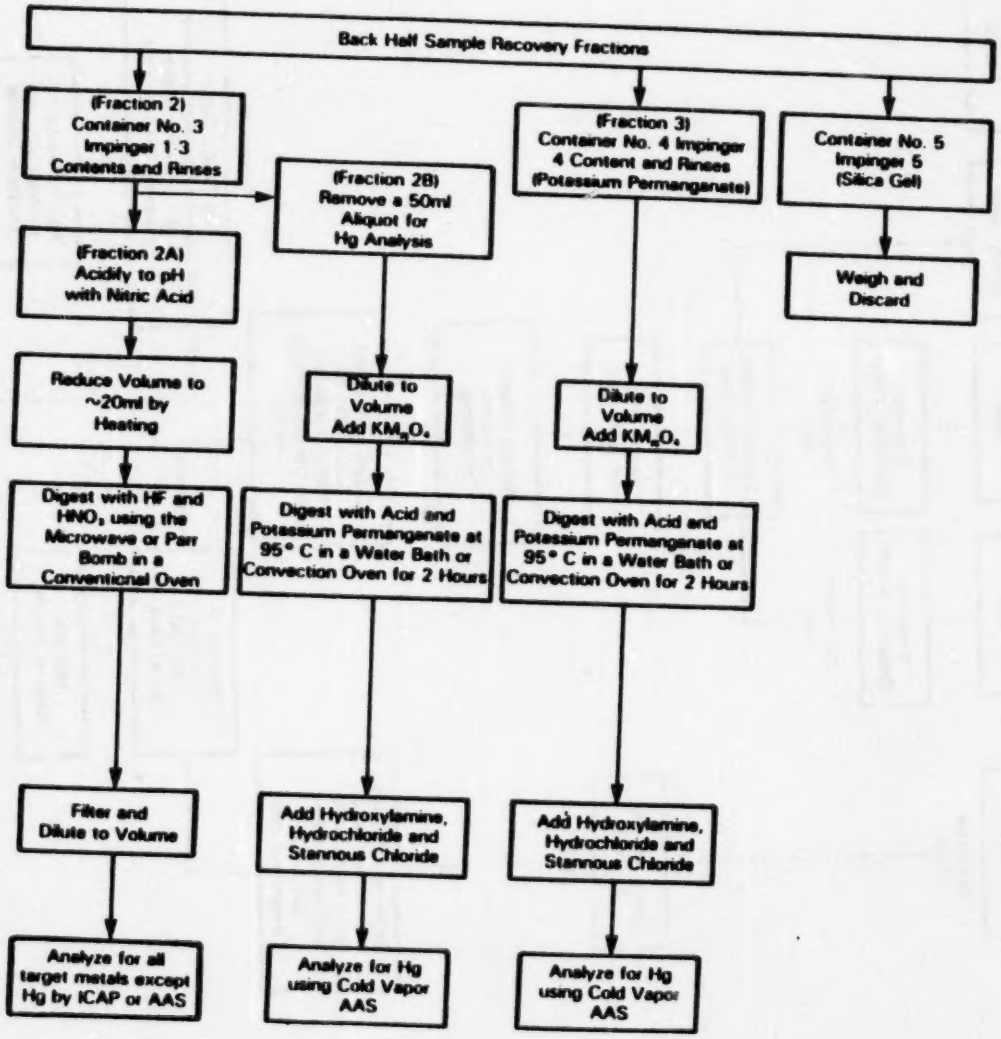

Back Half Sample Recovery Fractions
(Fraction 2) Container No. 3 Impinger 1 3 Contents and Rinses
(Fraction 2B) Remove a 50ml Aliquot for Hg Analysis
(Fraction 3) Container No. 4 Impinger 4 Content and Rinses (Potassium Permanganate)
Container No. 5 Impinger 5 (Silica Gel)
(Fraction 2A) Acidify to pH with Nitric Acid
Weigh and Discard
Reduce Volume to ~20ml by Heating
Dilute to Volume Add $KMnO_4$
Dilute to Volume Add $KMnO_4$
Digest with HF and HNO_3, using the Microwave or Parr Bomb in a Conventional Oven
Digest with Acid and Potassium Permanganate at 95° C in a Water Bath or Convection Oven for 2 Hours
Digest with Acid and Potassium Permanganate at 95° C in a Water Bath or Convection Oven for 2 Hours
Filter and Dilute to Volume
Add Hydroxylamine, Hydrochloride and Stannous Chloride
Add Hydroxylamine, Hydrochloride and Stannous Chloride
Analyze for all target metals except Hg by ICAP or AAS
Analyze for Hg using Cold Vapor AAS
Analyze for Hg using Cold Vapor AAS

Figure 5-2. Digestion and Analysis Scheme for Toxic Metal Train Components - Back Half

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SECTION 6

QUALITY ASSURANCE AND QUALITY CONTROL

This section discusses the quality assurance and quality control (QA/QC) program implemented for the project and the results obtained from analyzing the QA/QC samples. The objective of the QA/QC program is briefly discussed in the section below. Summaries of QC data are presented in Sections 6.2 through 6.2.3.

6.1 QA/QC PROGRAM OBJECTIVES

For any measurement effort there exists a degree of uncertainty due to the inherent limitations of the measurement system. The purpose of the QA program was to assess the magnitude of the degree of uncertainty in order to accurately assess the results obtained from these measurements. To meet this objective, the test plan was implemented and EPA reference methods or state-of-the-art sampling/analytical procedures for all critical measurements and QC activities were followed. The ultimate goal was to produce representative, complete, and comparable data of known quality.

The QA/QC program emphasized strict adherence to sampling and analytical procedures. The custody of the samples was monitored and the data were carefully documented. Sample matrices were spiked and spike duplicates analyzed to assess analytical method accuracy and precision. The QA/QC program provided a method for controlling data quality and to some extent the degree of uncertainty in the measurements system. The program also provided the basis for estimating the uncertainty by providing data for defining error limits. The QA objectives for each key parameter measured during the test program are shown in Table 6-1.

TABLE 6-1. SUMMARY OF ESTIMATED PRECISION, ACCURACY, AND DATA CAPTURE OBJECTIVES

Parameter (Method)	Precision	Accuracy	Data Capture[a]
Total Particulate (Toxic Metals Train)	± 11%[b]	± 10%[b]	90%
Flue Gas Metals	± 15%[c]	± 30%[d]	90%
Waste Feed Metals	± 15%[c]	± 30%[d]	90%
Velocity/Volumetric Flow Rate (EPA Method 1 and 2)	± 6%[b]	± 10%[b]	95%
Fixed Gases/Molecular Weight (Modified EPA Method 3)	± 10%[b]	± 20%[b]	90%
Moisture (EPA Method 4)	± 20%[b]	± 10%[b]	90%
Flue Gas Temperature (thermocouple)	± 2°F	± 5°F	90%

[a]Percentage of valid data compared to total tests conducted.

[b]Precision and accuracy estimate based on results of EPA Collaborative tests.

[c]Coefficient of variation (CV) for duplicate analyses, where

$$\% \text{ CV} = \frac{\text{Standard Deviation}}{\text{Mean}} \times 100$$

[d]Relative error (%) based on recovery of matrix spike analytes, where:

$$\% \text{ Relative Error} = \frac{\text{Measured Value} - \text{Spiked Value}}{\text{Spiked Value}} \times 100$$

6.2 METHOD-SPECIFIC QA/QC

The quality control procedures for feed material, front-half train, and back-half impinger samples included:

- Adherence to approved methods;
- Equipment calibration;
- Glassware and equipment cleaning;
- Sample custody procedures; and
- The use of matrix spikes, matrix spike duplicates, reagent blanks, and method blanks.

Quality control procedures and results are presented in this section. Procedures generally applicable to all sampling methods are discussed in Section 6.2.1. Results from metal analyses are presented in Sections 6.2.2 to 6.2.3.

6.2.1 General Quality Assurance and Quality Control Procedures

Estimated precision, accuracy and data capture objectives for this test program are summarized in Table 6-1. These objectives are based EPA collaborative test results, as well as on Radian's recent experience with the specific analytical procedures.

The custody of the samples was monitored and considered crucial in assessing sample integrity since samples were collected and analyses conducted in both the lab and the field. Samples were assigned unique identification numbers and integrity seals were affixed to sample containers. A master file of all samples collected was maintained and an informal log of daily activities was used to record other information concerning sampling activities.

Field equipment, including pitot tubes, nozzles, temperature measuring devices, and dry gas meters, were calibrated before and after field sampling as required by the sampling procedures used. Analytical balances were calibrated over the expected range of use with standard NBS weights. Daily calculations were made with QC weights previously checked with NBS traceable weights. All calibrations were documented on worksheets. Instruments used for atomic absorption (AA) and inductively coupled argon plasma (ICAP) analyses were calibrated according to the procedures recommended in the specific methods.

All sample train glassware, containers and tools were cleaned to minimize contamination. Cleaning procedures were specified in the project plan. Sample train glassware was capped after cleaning and immediately after each test. A clean environment was maintained for train assembly and recovery.

6.2.2 Particulate and Metal Sampling and Analysis

Sampling for particulate matter, toxic metals and surrogate metals was performed according to a modified version of Method 5, entitled "Methodology for the Determination of Trace Metal Emissions in Exhaust Gases from Stationary Source Combustion Processes." The results of isokinetic sampling rate calculations for the particulate/metals testing are presented in Table 6-2. Isokinetic sampling rates were clearly within the QC objective of 100 $\pm$ 10 percent for all of the inlet test runs and for the ESP outlet tests.

For the Hydro-Sonic outlet, isokinetic sampling rates are reported in Table 6-2 as a range due to uncertainty in the actual moisture content of the flue gas at this sample point. The Hydro-Sonic outlet sampling took place approximately 12' downstream of the system ID fan, which was immediately downstream of the Hydro-Sonics scrubber as shown in Figure 2-1. Flue gas entering the fan was saturated with water vapor at approximately

TABLE 6-2. SUMMARY OF GAS SAMPLING PARAMETERS AND CONDITIONS FOR PARTICULATE/METALS SAMPLING

TEST DATE	3/30/89	3/30/89	4/01/89	4/01/89	4/03/89	4/03/89	4/04/89	4/04/89	4/5/89	4/5/89	4/5/89	4/5/89
TEST RUN NUMBER	2	3	4	5	6	7	8	9	10	11	12	13
LOADING CONDITION	LOW	LOW	HIGH	LOW	HIGH	HIGH	LOW	LOW	LOW	LOW	LOW	LOW
PSD CONDITION	LOW	HIGH	HIGH	HIGH	LOW	HIGH	LOW	LOW	LOW	LOW	LOW	LOW
INLET												
TIME	11:02-11:32	15:52-17:07	11:32-13:55	15:39-17:49	10:03-13:03	14:56-17:05	11:58-14:05	16:41-19:24	11:12-12:20	13:49-15:02	16:12-17:24	Not Sampled
STACK TEMP. (F)	500	520	473	449	476[b]	507	497	488	515	523	523	
OXYGEN (%V)	7.3[b]	6.1	8.7	8.2	6.5	6.5	5.2	4.1	5.3	5.8	5.1	
STACK MOISTURE (%V)	59.4	55.4	51.3	51.8	53.8	57.2	56.3	58.6	57.0	57.3	58.4	
VOL. FLOW RATE (ACFM)	3088	3332	3467	3555	2996	3366	3221	3144	3551	3556	3565	
VOL. FLOW RATE (DSCFM)	658	764	918	953	740	746	747	697	830	821	801	
PERCENT ISOKINETIC	112.5	101.8	87.4	87.9	95.1	101.3	101.4	108.0	103.2	103.6	105.5	
OUTLET												
TIME	10:58-13:19	15:51-18:27	11:35-14:21	15:42-18:21	10:10-13:39	14:50-17:33	11:56-14:39	16:41-19:46	11:12-12:46	13:49-14:59	16:12-17:20	18:06-19:11
STACK TEMP. (F)	150	139	226[b]	223	230	230	225	228	224	233	233	237
OXYGEN (%V)	17.8	18.0	8.5[b]	8.8	6.7	7.2	7.1	5.9	7.0	6.5	7.1	6.2
STACK MOISTURE (%V)	28.9	22.7	53.2	53.8	55.4	54.5	57.4	58.7	56.6	57.1	58.3	59.2
VOL. FLOW RATE (ACFM)	210	226	2630	2746	2338	2514	2551	2666	2881	2842	2891	2870
VOL. FLOW RATE (DSCFM)	120	142	942	971	783	858	834	841	966	931	921	890
PERCENT ISOKINETIC[a]	95.8	98.3	99-114	104-118	108-124	102-116	101-120	96-116	108-120	107-120	112-124	112-126

[a] See discussion in Qa/QC section for explanation of isokinetic ranges.

[b] Value recorded from plant process data. Emission testing value was considered suspect.

181°F and -55 inches of water static pressure. Calculations, using steam tables, show saturation moisture at these conditions to be approximately 59 percent water vapor.

As the flue gas passed through the fan, the static pressure increased to +6 inches of water (measured at sampling location) and the gas temperature ncreased to approximately 225°F. This increase in pressure caused some moisture to condense and occasionally was drained through a drain plug in the fan housing. Although the temperature increase across the fan would appear to be great enough to allow all moisture to revaporize, this did not happen as on-site observation showed the stack gas to be laden with entrained water droplets.

If none of the water were revaporized, flue gas at the fan outlet would have been saturated at 181°F and +6 inches of water static pressure. Calculations from steam tables show saturation content at this condition to be approximately 50 percent water vapor by volume. Thus, the degree of saturation actually lies somewhere between 50 and 59 percent.

Using the 50 percent value, isokinetics sampling rates for the Hydro-Sonic outlet range from 96 to 107 percent, which is within the QC objective. Using the 59 percent moisture content (based on saturation at the fan inlet), the isokinetic sampling rates for the Hydro-Sonic outlet range from 114 to 124 percent, which exceeds the QC objective.

A moisture content of 50 percent was used on-site to determine sampling rates because of the obvious presence of entrained moisture at the stack. However, after reviewing the data, it was decided to present isokinetic results as a range, with the upper value calculated from the total mass of moisture collected in the impinger train. Since only sub-micron particles are expected to escape control by the Hydro-Sonic scrubber, particulate/metals results would not be significantly biased by sampling non-isokinetically because the sub-micron particles would be have as a gas.

Leak checks were performed before and after each port change. All the Particulate/metals sampling trains met the QA criteria of a leak rate less than or equal to 0.02 acfm. The leak rate data can be found on the field data sheets in Appendix C.1.

Analysis for metals was performed by either inductively coupled argon plasma (ICAP) or by atomic absorption (AA). Matrix spike, matrix spike duplicate, method blank and reagent blank results are presented in Tables 6-3 Through 6-6. Previously analyzed field samples were spiked with a known concentration of the target metals to yield the matrix spike samples. The spikes were duplicated to provide analytical recovery and precision information.

The QC objective for the metals analysis was ± 30 percent recovery. Review of the data in Table 6-3 shows excellent matrix spike recoveries, ranging from 80 to 113 percent for all of the target metals. Agreement between duplicate matrix spikes also shows excellent analytical precision for the metals analysis.

The method and reagent blanks for all samples were clean. All results were reported as less than the detection limits, which were dependent on the metal and sample volumes.

6.2.3 HCl Sampling and Analysis

During HCl sampling, leak checks were also performed before and after each port change. All leak checks met the leak check QC criteria. A matrix spike, matrix spike duplicate, reagent blank, and matrix blank were analyzed along with the HCl field samples. Chloride recoveries for the two matrix spikes were 105 and 99 percent, which is acceptable. The reagent blank and the laboratory blank were both clean, with chloride contents below the detectable level of 2 mg/L.

TABLE 6-3. MATRIX SPIKE AND MATRIX SPIKE DUPLICATE RESULTS FOR METAL ANALYSES

Sample Type	Metal	Percent Recovery	
		Matrix Spike	Matrix Spike Duplicate
Front Half	As	113	110
	Bi	100	100
	Cd	100	100
	Cr	95	95
	Cu	95	95
	Hg	80	79
	Mg	112	109
	Pb	109	105
	Sr	112	109
Back Half Impingers 1, 2,& 3	As	105	105
	Bi	100	100
	Cd	105	105
	Cr	100	100
	Cu	95	95
	Hg	100	100
	Mg	100	100
	Pb	112	109
	Sr	105	105
Back Half Hg Impinger 4	Hg	92	96
Waste Feed	As	97	94
	Bi	110	105
	Cd	93	93
	Cr	94	98
	Cu	95	93
	Hg	102	--
	Mg	98	98
	Pb	100	96
	Sr	94	94

TABLE 6-4. METHOD AND REAGENT BLANK RESULTS FOR METAL SAMPLE ANALYSES - FRONT HALF SAMPLES

Metal	Method Blank (total ug)	Reagent Blank (total ug)
As	< 2.30	< 2.30
Bi	< 800	< 800
Cd	< 5.00	< 5.00
Cr	< 30.0	< 30.0
Cu	< 20.0	< 20.0
Hg	< 2.90	< 2.90
Mg	< 1000	< 1000
Pb	< 2.57	< 2.57
Sr	< 3.00	< 3.00

TABLE 6-5. METHOD BLANK AND REAGENT BLANK RESULTS FOR METAL SAMPLES - BACK HALF IMPINGERS 1,2,3,4

Sample	Metal	Method Blank (total ug)	Reagent Blank (total ug)	
Impingers 1,2,3	As	< 0.288	< 0.296	<0.294
	Bi	< 100	< 103	< 102
	Cd	< 0.625	< 0.643	<.639
	Cr	< 3.75	< 3.86	< 3.84
	Cu	2.50[a]	< 2.57	< 2.56
	Hg	< 0.540	< 0.243	< .248
	Mg	< 125	< 129	< 128
	Pb	< 0.321	< 0.331	< 0.329
	Sr	0.500[a]	< 0.386	0.384[a]
Impinger 4	Hg	< 0.460	< 0.217	

[a]Less than five times the detection limit.

TABLE 6-6. METHOD BLANK RESULTS FOR METAL SAMPLE ANALYSES - WASTE FEED

Metal	Method Blank (ug/g)
As	< 0.460
Bi	< 160
Cd	1.80[a]
Cr	< 6.00
Cu	8.00[a]
Hg	< 1.25
Mg	< 200
Pb	1.09[a]
Sr	1.00[a]

[a]Less than fives times the detection limit.